EXHIBIT "A"

ELECTRO-OPTICAL CABLE FOR USE IN TRANSMISSION OF HIGH VOLTAGE AND OPTICAL SIGNALS UNDER EXTREMES OF TEMPERATURE AND ALTITUDE

Statement of Government Interest

The invention described herein was made under Contract No. N0019-96-C005 with the Government of the United States of America and may be manufactured and used by and for the Government of the United States of America for Governmental purposes without the payment of any royalties thereon or therefor.

Background of the Invention

1. Field of the Invention

The present invention relates to towed decoys for use in aviation, and more particularly to electro-optical cables for use in such towed decoys.

2. Brief Description of Prior Developments

It is known in the art to provide a decoy which is towed on an electro-optical cable from a combat aircraft. While such arrangements have generally performed well, there is a need to still further improve the temperature, mechanical, electrical and environmental durability of such electro-optical cables.

Summary of Invention

The present invention is an electro-optical signal cable which has improved the temperature, mechanical, electrical, and environmental durability. Volumetric and weight impacts are minimized, thus significantly extending applicability beyond current existing design limitations.

Improved durability has been achieved by acknowledging the three distinct elements of the cable and addressing each separately then merging the elements into a single design. The constituent layers are combined in a synergistic manner. The electrical conductors make use of adhesive materials in order to fuse the dielectric materials to the wire. The resulting wire construction method demonstrates excellent dielectric withholding potential, over 5 kV, at temperatures of up to 700 degrees Fahrenheit. The fiber optic element has been improved through consideration of the optical fiber as a portion of a composite beam, in which the fiber was encased in a cushion of PTFE, Polytetrafluorethylene, TEFLON, then a thermo-plastic resin, PEEK, Polyetheretherketone, was utilized to provide a tough, hard, outer shell which improved both thermal and mechanical durability to levels in excess of 700 degrees Fahrenheit. The electrical conductors have layers of dielectric PTFE and aromatic co-polyimides such as BPDA-PDA and PMDA-ODA. The conductors are copper with a plating of a diffusion barrier such as nickel. The braid selected consisted of a PBO, Poly(p-phenylene-2,6-benzobisoxazole), Zylon, outer jacket with a friction reducing coating included to aid in deployment of the material. The resulting cable system has proven performance when subjected to the rigors of the after-burning plume of a jet engine installed in the Navy's F/A-18E/F fighter aircraft. Research performed in the conduct of the development of the advanced durability cable has lead to the potential for further increases to thermal and mechanical performance through the use of advanced polymers such as Upilex-S and other co-polymers based on aromatic polyimides such as BPDA-PDA and PMA-ODA and films made of PBO, basic material only testing indicates a

further enhancement in performance. The application method would be the same as that for the cable claimed herein, thus is a further claim of this patent disclosure.

Brief Description of the Drawings

The present invention is further described with reference to the accompanying drawings, wherein:

Figure 1 is a vertical cross sectional view of the electro-optical cable of the present invention.

Detailed Description of the Preferred Embodiment

A preferred embodiment of the present invention is described with reference to Figure 1 and Table 1. The reference numbers on Figure 1 are identified on Table 1.

Signal-Conductors		
	Baseline	**Upgrade**
1	**32 Ga Copper**	**PTFE**
2	**MIL-ENE** 0.002"/0.003"	**PTFE** 0.0005"
3	**N/A**	**EKJ** 0.003" 0.004" 0.006"

Signal-Optics		
	Baseline	**Upgrade**
4	**Glass**	**Glass**
5	**Acrylate** 245 microns	**Polymide** 152 microns
6	**PTFE** 0.003"	**PTFE** 0.003"
7	**FEP** 600 micron OD	**PFA and PEEK** 600 micron OD

Table 1

A further disclosure and a preferred embodiment and tests showing surprising and unexpected results are shown in the following attached exhibits:

Exhibit "A"	Tow/Signal Line Development
Exhibit "B"	Phase C Thermal Upgrade Towline Flight Test Review
Exhibit "C"	Past Flight Tow/Signal Line Analysis

It will be appreciated that an electro-optical cable has been described which is durable under adverse temperature, mechanical, electrical and other environmental conditions.

While the present invention has been described in connection with the preferred embodiments of the various figures, it is to be understood that other similar embodiments may be used or modifications and additions may be made to the described embodiment for performing the same function of the present invention without deviating therefrom. Therefore, the present invention should not be limited to any single embodiment, but rather construed in breadth and scope in accordance with the recitation of the appended claims.

Claims

What is claimed is:

1. An electro-optical cable comprising:

an optical element comprising an elongated glass fiber core, a medial cushioning layer concentrically surrounding the glass fiber core, and an outer hard shell material surrounding the medial cushioning layer; and

at least one electrically conductive element comprising an elongated conductive core and a dielectric layer concentrically surrounding the electrically conductive element.

2. The electro-optical cable of claim 1 wherein the medial cushioning layer of the optical element comprises polytetrafluorethylene.

3. The electro-optical cable of claim 1 wherein the outer hard shell layer of the optical element comprises polyetheretherketone.

4. The electro-optical cable of claim 1 wherein the conductive core of the electrically conductive element comprises copper.

5. The electro-optical cable of claim 1 wherein the dielectric layer of the electrically conductive element comprises dielectric polytetrafluorethylene.

6. The electro-optical cable of claim 1 wherein the electrically conductive element has a layer of an aromatic co-polyimide concentrically surrounding the dielecetric layer.

7. The electro-optical cable of claim 1 the wherein optical element has a layer selected from an acylate and a polymide interposed between the glass core and the cushioning layer.

Abstract

An electro-optical cable comprising an optical element comprising an elongated glass fiber core, a medial cushioning layer concentrically surrounding the glass fiber core, and an outer hard shell material surrounding the medial cushioning layer; and at least one electrically conductive element comprising an elongated conductive core and a dielectric layer concentrically surrounding the electrically conductive element.

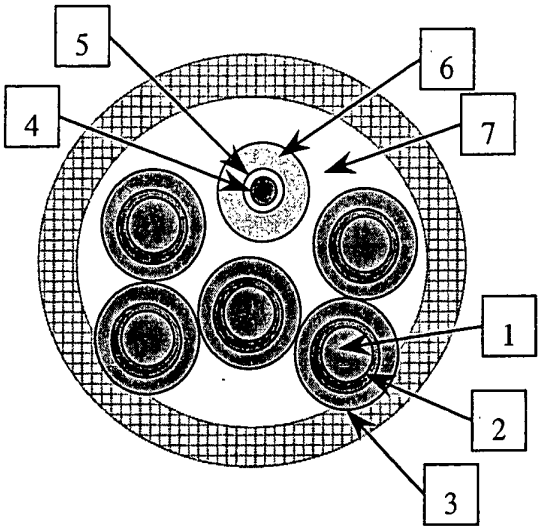

Figure 1

BAE SYSTEMS

Tow/Signal Line Development

Dr. John Dion

Exhibit "A"

Baseline Tow/Signal Line Development History

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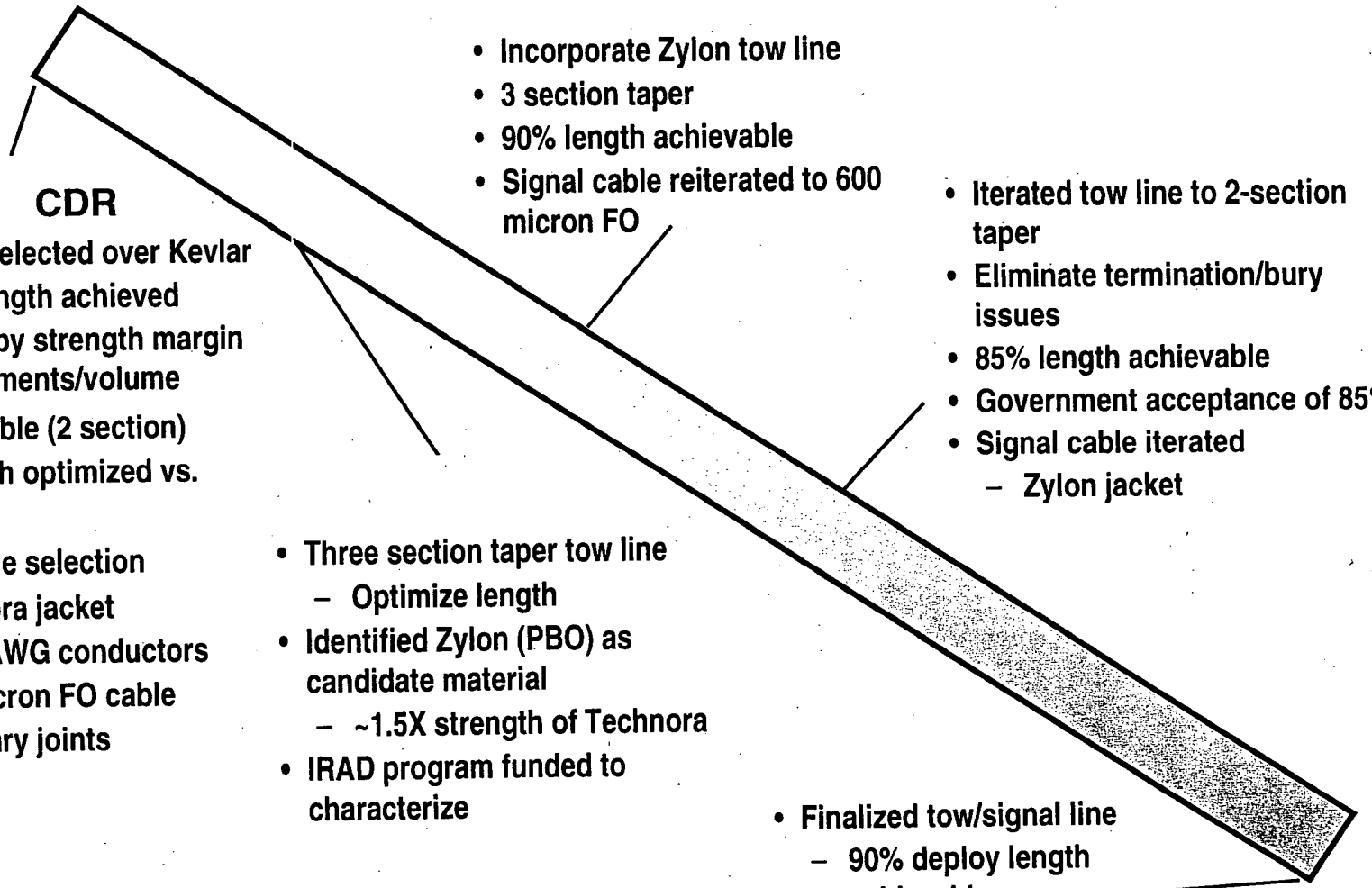

CDR

- Technora selected over Kevlar
- 86% tow length achieved
  - Driven by strength margin requirements/volume
- Tapered cable (2 section)
  - Strength optimized vs. length
- Signal cable selection
  - Technora jacket
  - 5 - 32 AWG conductors
  - 250 micron FO cable
  - No rotary joints

- Three section taper tow line
  - Optimize length
- Identified Zylon (PBO) as candidate material
  - ~1.5X strength of Technora
- IRAD program funded to characterize

- Incorporate Zylon tow line
- 3 section taper
- 90% length achievable
- Signal cable reiterated to 600 micron FO

- Iterated tow line to 2-section taper
- Eliminate termination/bury issues
- 85% length achievable
- Government acceptance of 85%
- Signal cable iterated
  - Zylon jacket

- Finalized tow/signal line
  - 90% deploy length achievable
- HM - Zylon w/fiberline lubrication

Baseline Cable Design

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- Towline
  - Zylon-HM
    - High modulus, reduce strain @ load
    - Reduce load transmitted to wrapped signal cable
  - Two segment taper
    - 0.040", 0.052" diameter (600 and 900 lb strength)
    - Better than 150% strength margin (1.9)
  - Fiberline friction reducing coating applied (sizing of fibers) produces significant improvements in terms of abrasion resistance

Signal Line

- Zylon-HM
- 5 x 32 AWG Cu conductors and 600 micron FO
- 0.045" diameter (160 lb strength)
- Better than 200% strength margin (2.8)
- Fiber Optic safety factors >200% UTS data
- Fiberline friction reducing coating

Baseline (Standard) Tow/Signal Cable

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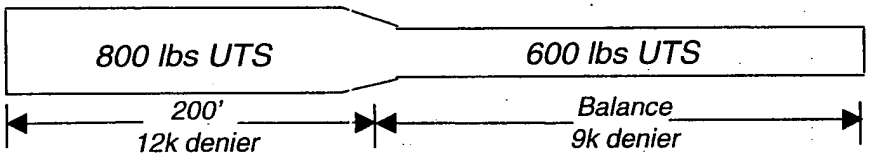
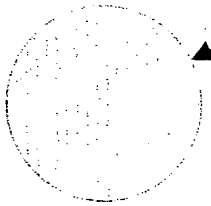
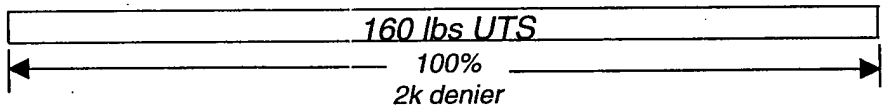
Tow Cable

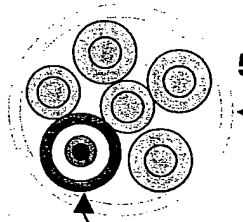




Tow
2 Stage
12k / 9k denier Zylon

Signal Cable





Signal Jacket
2k denier Zylon

Signal Conductors
32 Ga copper
MIL-ENE 0.002" / 0.003"

Signal Optics
Acrylate 245 microns
PTFE 0.004"
FEP 0.004"

- Packaged Length
  - Tow 98% Spec
  - Signal 93% Spec
- Deployable Length = 90% Spec

  Deploy Length (Flight Tested) = 85% Spec

Reason for High Temperature Cable

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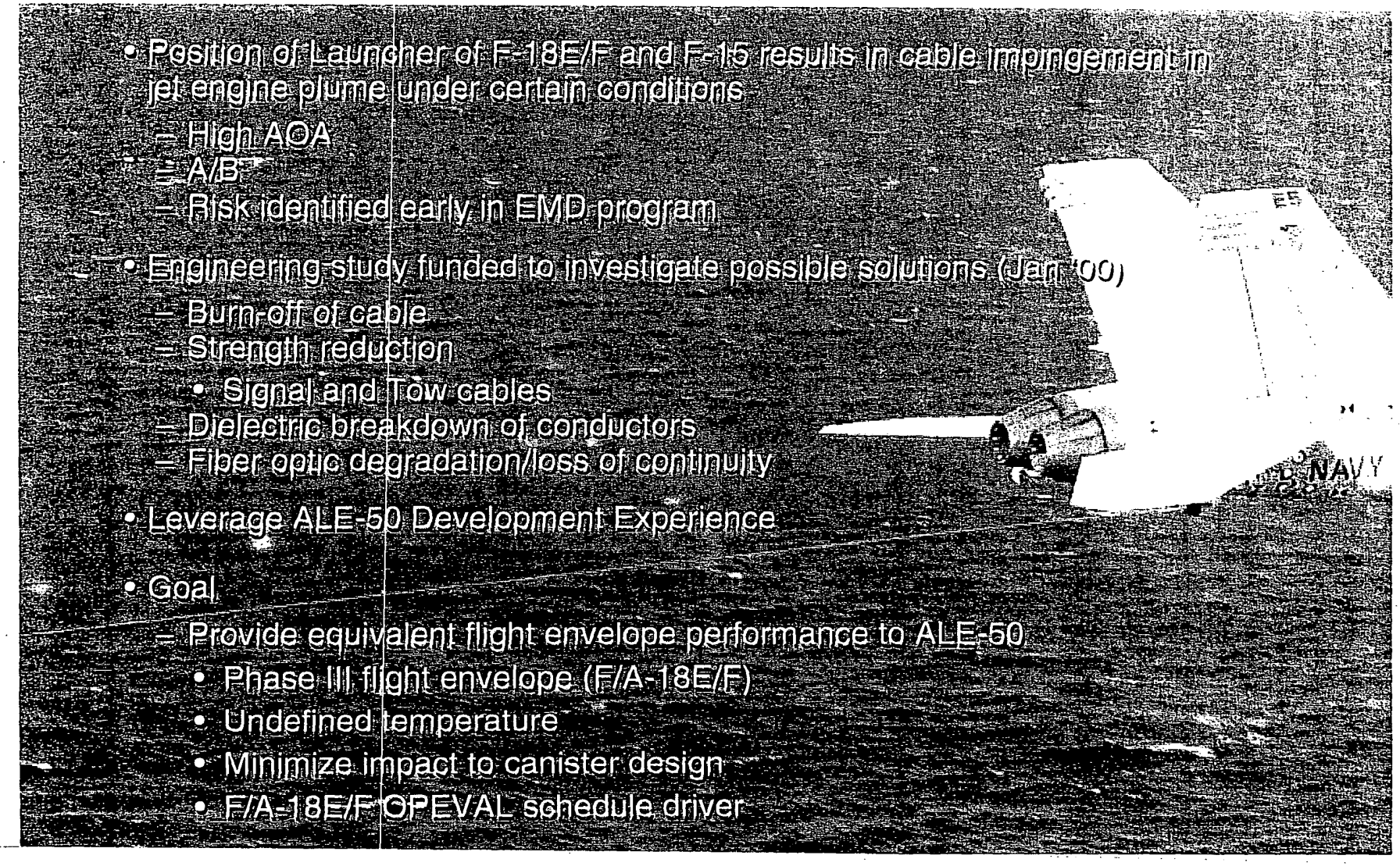

- Position of Launcher of F-18E/F and F-15 results in cable impingement in jet engine plume under certain conditions
  - High AOA
  - A/B
  - Risk identified early in EMD program
- Engineering study funded to investigate possible solutions (Jan '00)
  - Burn-off of cable
  - Strength reduction
    - Signal and Tow cables
  - Dielectric breakdown of conductors
  - Fiber optic degradation/loss of continuity
- Leverage ALE-50 Development Experience
- Goal
  - Provide equivalent flight envelope performance to ALE-50
    - Phase III flight envelope (F/A-18E/F)
    - Undefined temperature
    - Minimize impact to canister design
    - F/A-18E/F OPEVAL schedule driver

Towline Thermal Upgrade Program

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- Three phase development plan established to upgrade IDECM Cables
  - F/A-18E/F installation requires thermally ruggedized tow/signal line
  - Objective is to meet/exceed Phase III envelope established for F/A-18E/F OPEVAL
- Phase 0 - characterization effort
  - Baseline ALE-55 vs. ALE-50 cable comparison test - complete
  - Performance drivers are strength and HV hold-off at elevated temperature

  Phase 1 Lab development effort (Jun 00)
  - Cable/material development
    - -- Strength member, HV conductors and FO
  - Development focus on available materials (organic/inorganic polymers)
    - -- Candidates identified and in test
  - HV mass model feasibility evaluation
  - Evaluation of system/FOTD round impacts
    - -- Line length, multiple deploy lengths
- Phase 2 Flight development effort (Nov 00)
  - Material characterization
  - Canister implementation
  - Assets available for initial flight testing

Baseline Cable Plume Damage

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- F/A-18E/F Fast Deploy Test
- Plume induced heat damage during low AOA A/B maneuver
  - 2 seconds plume impingement
    - MILENE melted -> wire shorting
    - Fiber coatings flowed -> loss of optical continuity
- Laboratory testing shows milene melting begins @ 300°C

Baseline Cable Plume Damage

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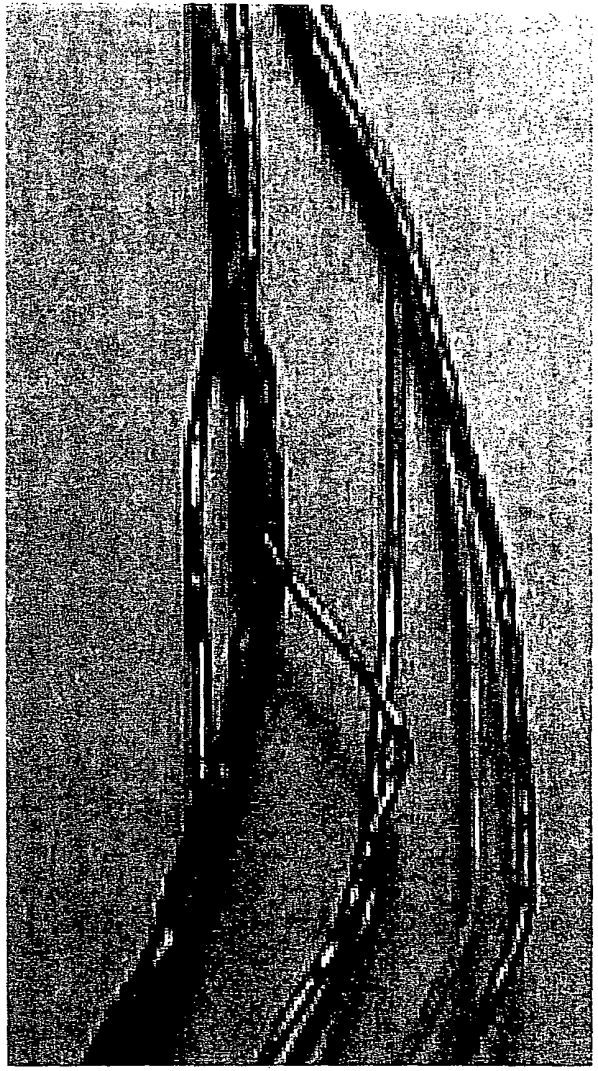
- F-15 Safe Separation Flights (Phase 3A)

  Plume induced A/B heat damage

  – MILENE softened which resulted in shorting
  – Fiber coatings flowed causing loss of optical continuity



Materials/Effects for Plume Endurance

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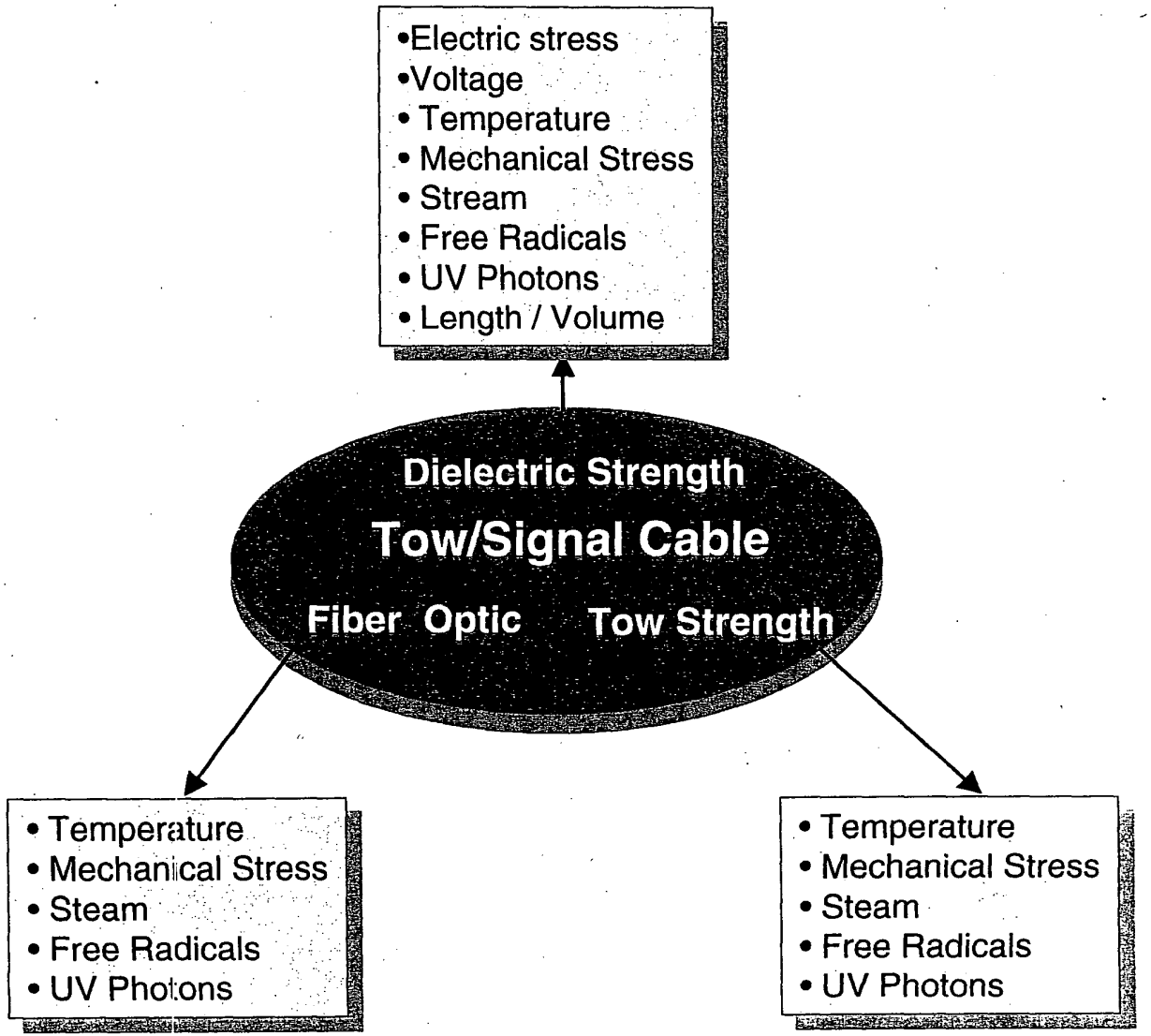

The Optimization Problem

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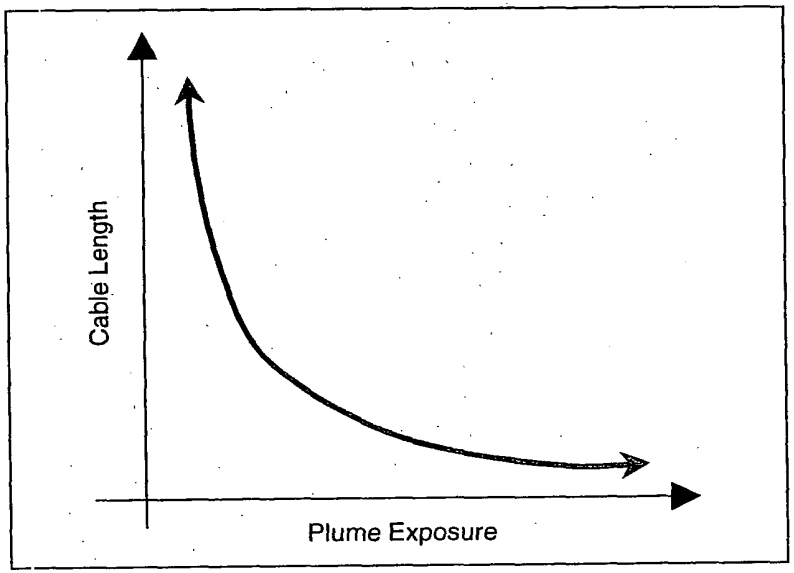
Maximizing cable length consists of minimizing:

- Dielectric coating
- Fiber optic coating
- Zylon signal jacket thickness
- Zylon tow diameter

• Maximizing plume exposure would minimize length



Dielectric (Conductor Insulation) Candidates

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Extensive literature search, vendor correspondence, and consultant involvement

- Parallel study efforts (MIT/EWAT & NRL)
- GE Corporate Research and Development

Options Evaluated/Tested

- Ceramics
- Glasses
- Hybrids
- Teflon
- Kapton Variations

Selected Test Results (Dielectric)

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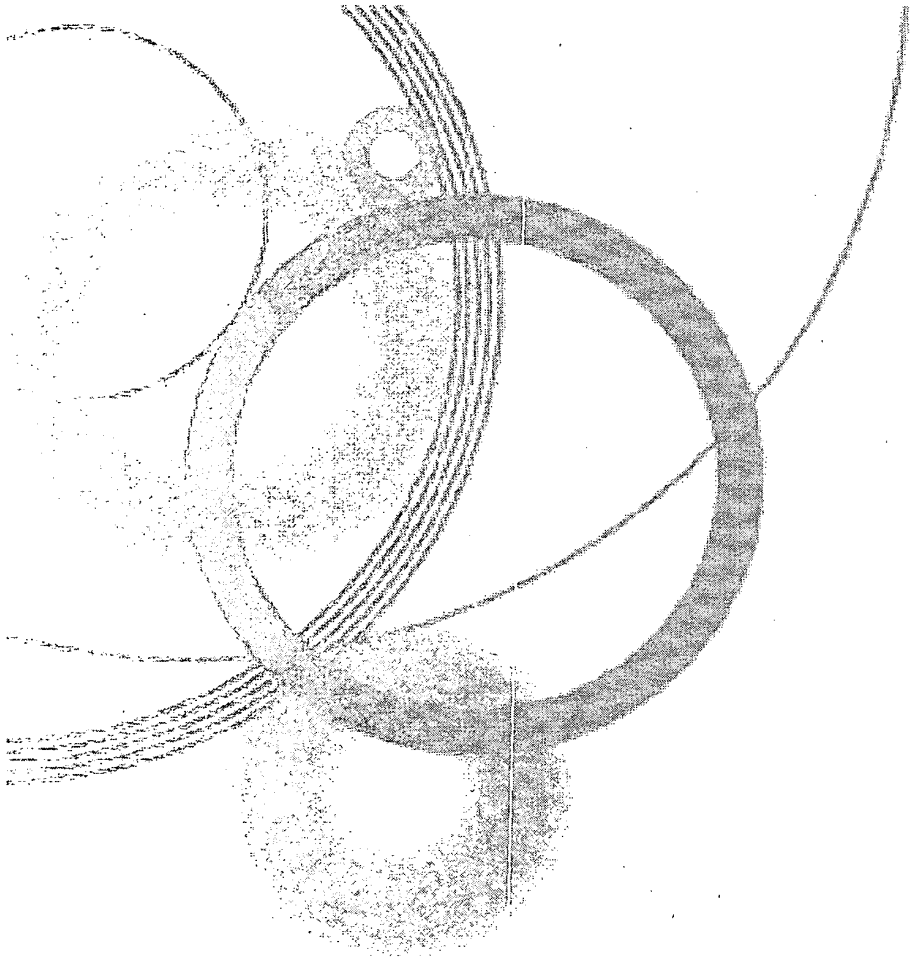
Polymer Dielectric Performance (Top Tier Candidates)

– Based on BAE SYSTEMS electrode testing (10 min, no load)

Film (polymer)	Dielectric Breakdown Voltage @ temp (KV/mil)					5KV / 500 °C Insulation Required (mils)
	300 °C	400 °C	500 °C	550 °C	600 °C	
Teflon (PTFE)	0.8	0.65	0.45*	N/A	N/A	11.0
Kapton H (PMDA-ODA)	3.0	2.0	0.71	0.025*	N/A	7.0
Kapton E (BPDA-PDA//PDMA-ODA)	2.0	1.1	0.75	0.625*	N/A	6.7
Upilex-S (BPDA-PDA)	2.0	1.5	0.95	0.7	0.43*	5.0

* Temperature onset for brittleness / high shrinkage / degradation

EXHIBIT "B"



BAE SYSTEMS

Phase C
Thermal Upgrade Towline
Flight Test Review

Exhibit "B"

Agenda

BAE SYSTEMS

• Introduction/Objectives	B. Sarantis	PM
• Canister Configuration	B. Sarantis	PM
• Flight Test Report	D. Davidson	PEM
• Post Flight Hardware Analysis	B. Sarantis	PM
• Post Flight Tow/Signal Line Analysis	Dr. J. Dion	Eng. Fellow
• Conclusions/Recommendations	B. Sarantis	PM

Objectives

BAE SYSTEMS

- Review Towline Phase C Test Results
- Review Findings
- Discuss Recommendations Going Forward

Program Background

BAE SYSTEMS

- **Thermal Upgrade Not Part of EMD Contract**
- **Navy Recognized Need to Pursue Enhancement**
  - Funded Off Contract Effort
  - Specific to F-18E/F Aircraft

  Engineering Study
  - Evaluate Materials for High Temperature Use
    - ✓FO Coatings
    - ✓Dielectric Material
    - ✓Strength Members
  - Perform Laboratory Testing
  - Select Candidate Tow/Signal Line Configurations
- **Conduct Flight Tests**
- **Down Select To Final Configuration**
- **Support Proof of Concept Flight Tests**

Executive Summary

BAE SYSTEMS

- **Highlights**
  - Demonstrated Excellent Thermal Performance
    - ✓ ***No*** Thermally Induced Failures Within Goal Envelope
  - Eliminated FO Failures During Deployment
  - Demonstrated Excellent System Performance During Mission/Combat Representative Maneuvering
  - Verified ALL Corrective Actions Implemented From Previous Phases
    - ✓ BAE Snubber vs. Greene Rubber Snubber
    - ✓ Brake Assembly Acceptance Criteria
- **Challenges Remaining**
  - "No Hit" Separation
  - Resolution to "High Twist" Mechanical Failures

BAE SYSTEMS

Canister Configuration

B. Sarantis

Canister Configuration Summary

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- **Phase C Mass Model Round P/N 6273250G6**
- **Similar to Baseline Mass Model Round Except:**
  - Utilizes High Voltage Mass Model
  - Thermally Upgrade Tow and Signal Line
  - Teflon Impregnated Rounded Fins
  - Upgraded Fin Damper Mechanism
    - ✓ 275 msec Time Delay

Tow/Signal Line Configuration

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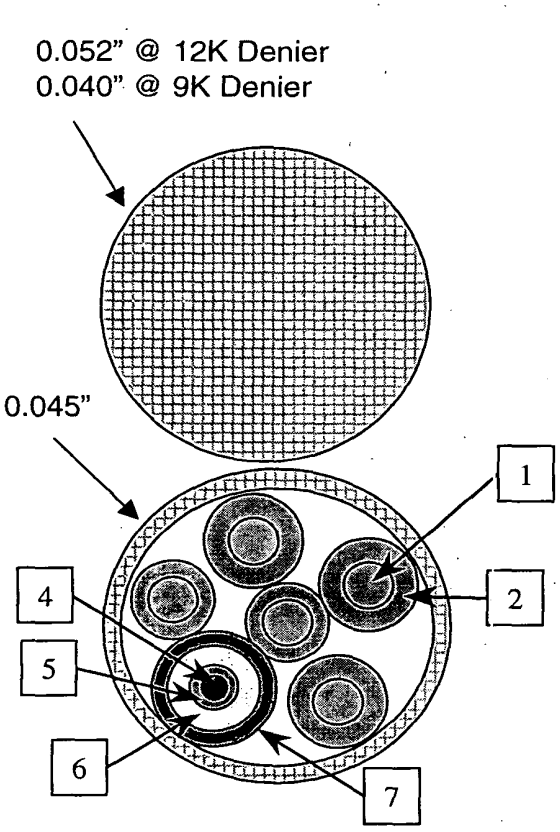


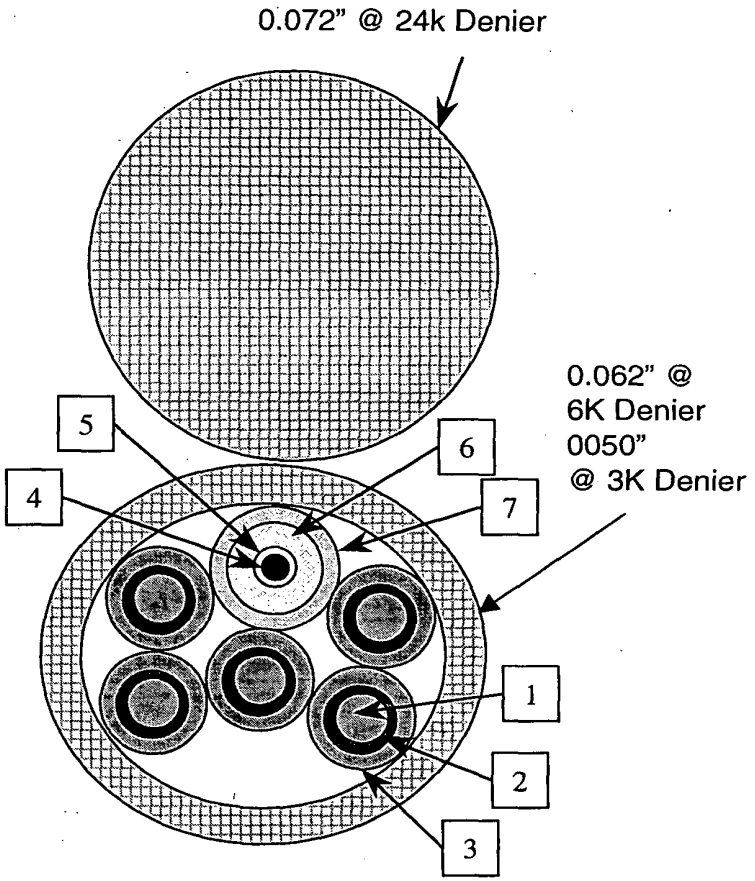
Baseline Cable System

Tow	
Baseline	**Upgrade**
2 Stage	3 Stage
12k / 9k denier	24k / 12k / 9k denier

Signal - Jacket	
Baseline	**Upgrade**
2k denier	6k / 3k denier

Signal - Conductors		
	Baseline	**Upgrade**
1	**32 Ga copper**	**32 Ga copper**
2	**MIL-ENE** 0.002" / 0.003"	**PTFE** 0.0005"
3	**N/A**	**EKJ** 0.004"

Signal - Optics		
	Baseline	**Upgrade**
4	**Glass**	**Glass**
5	**Acrylate** 245 microns	**Polyimide** 152 microns
6	**PTFE** 0.003"	**PTFE** 0.003"
7	**FEP** 600 micron OD	**PEEK** 600 micron OD



Tow/Signal Line Configuration

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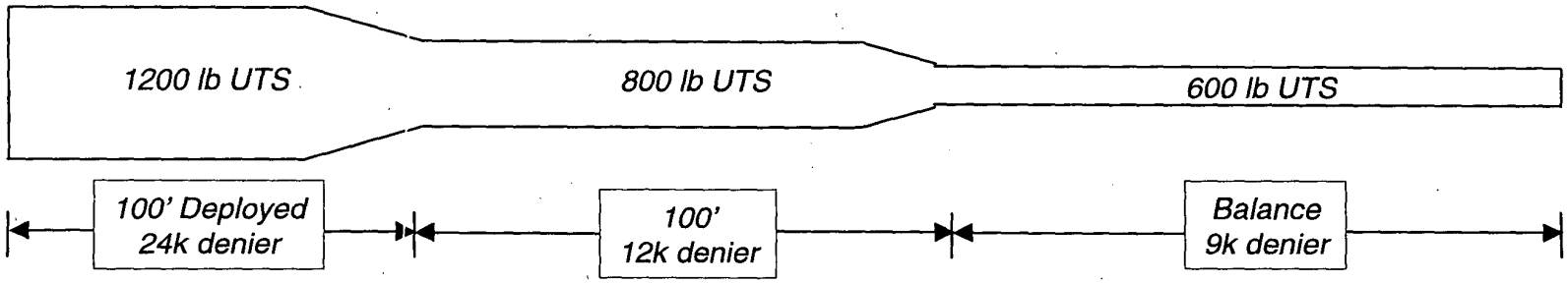
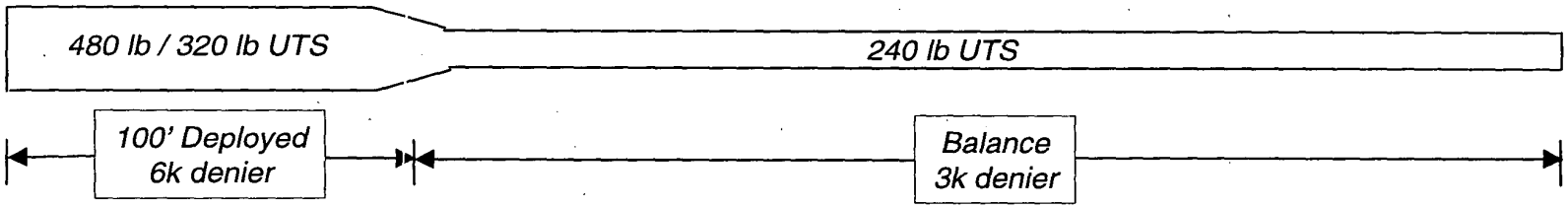
Tow Cable



Signal Cable Jacket



Packaged length

- Tow 72% (vs original spec)
- Signal 60% (vs original spec)

- **Deploy Length = 58% (vs original spec)**

- **Worst Case Margin (@ 58%)**
  - Tow: 3.3
  - Signal: 3.6
    - ✓ Glass better than 2.0

BAE SYSTEMS

Flight Test Report

D. Davidson

Phase C Test Objectives

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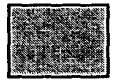
- **Evaluate Selected Tow/Signal Line Throughout F/A-18E/F Flight Envelope**
  - ALE-50 Phase III Envelope Restrictions
- **Evaluate Overall Canister / Round Performance**
  - Launch, Deploy, Continuity and Tow
- **Evaluate Safe Separation Performance**
  - F/A-18E/F



Flight Test Configuration

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- **Platform**
  - F/A-18 F2 (Flights 1-3)
  - F/A-18 E5 (Flights 4-10)
- **High Speed Cameras**
- **Conventional Installation**
- **Center Line Tank Included For Some Deployments**

- **System Components**
  - RFCM
  - IMPLC
  - BCC
    - ✓SW Version 2.3.B.B
      - ⇒ 58% Deployment Length
  - T-3F Launcher
    - ✓Fuselage Installation
  - HVS Box
  - Production Towline Extension

Thermal Upgrade Canister Demonstrated Flight Envelope

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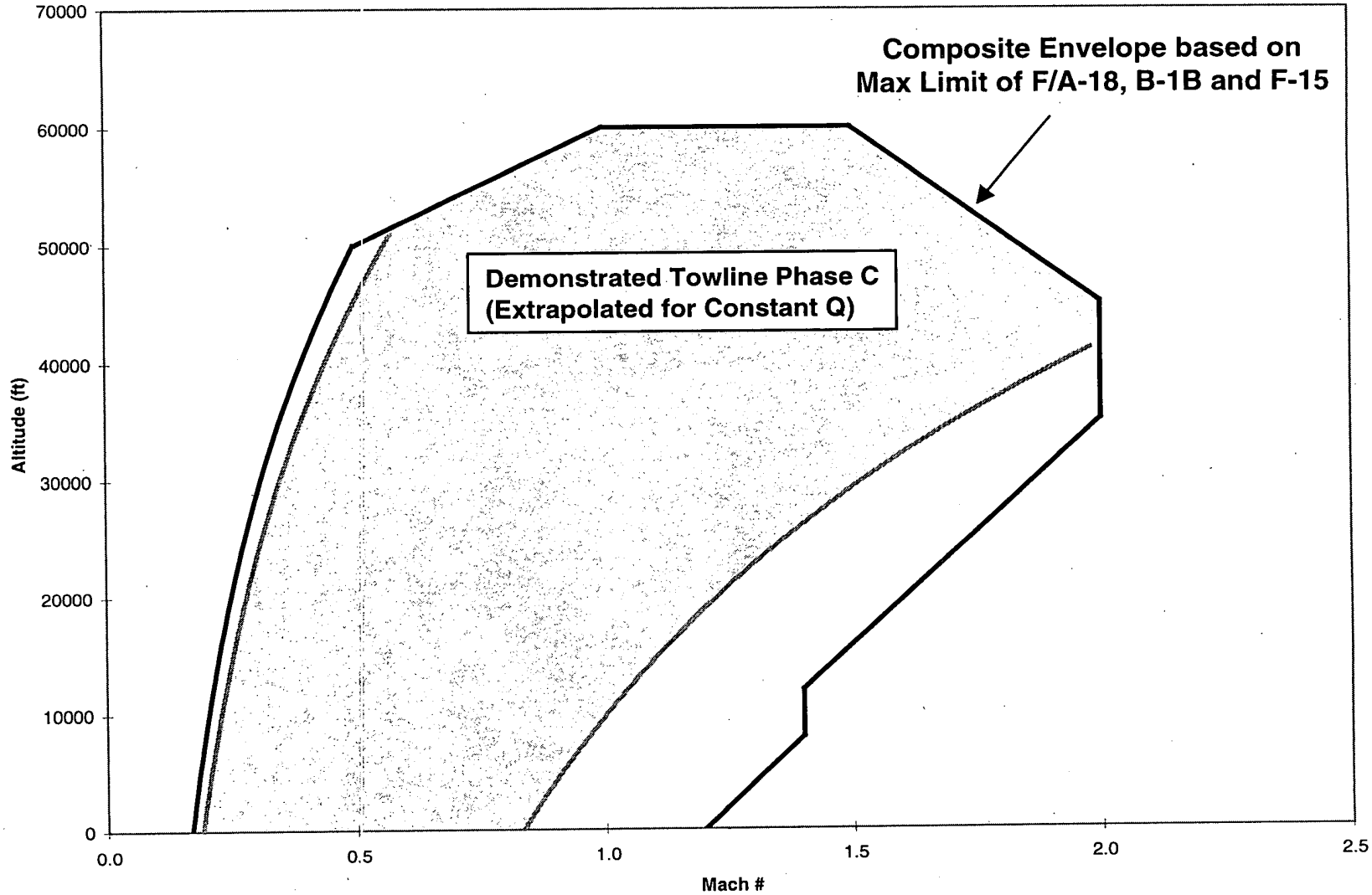

Representative Flight Test Profiles

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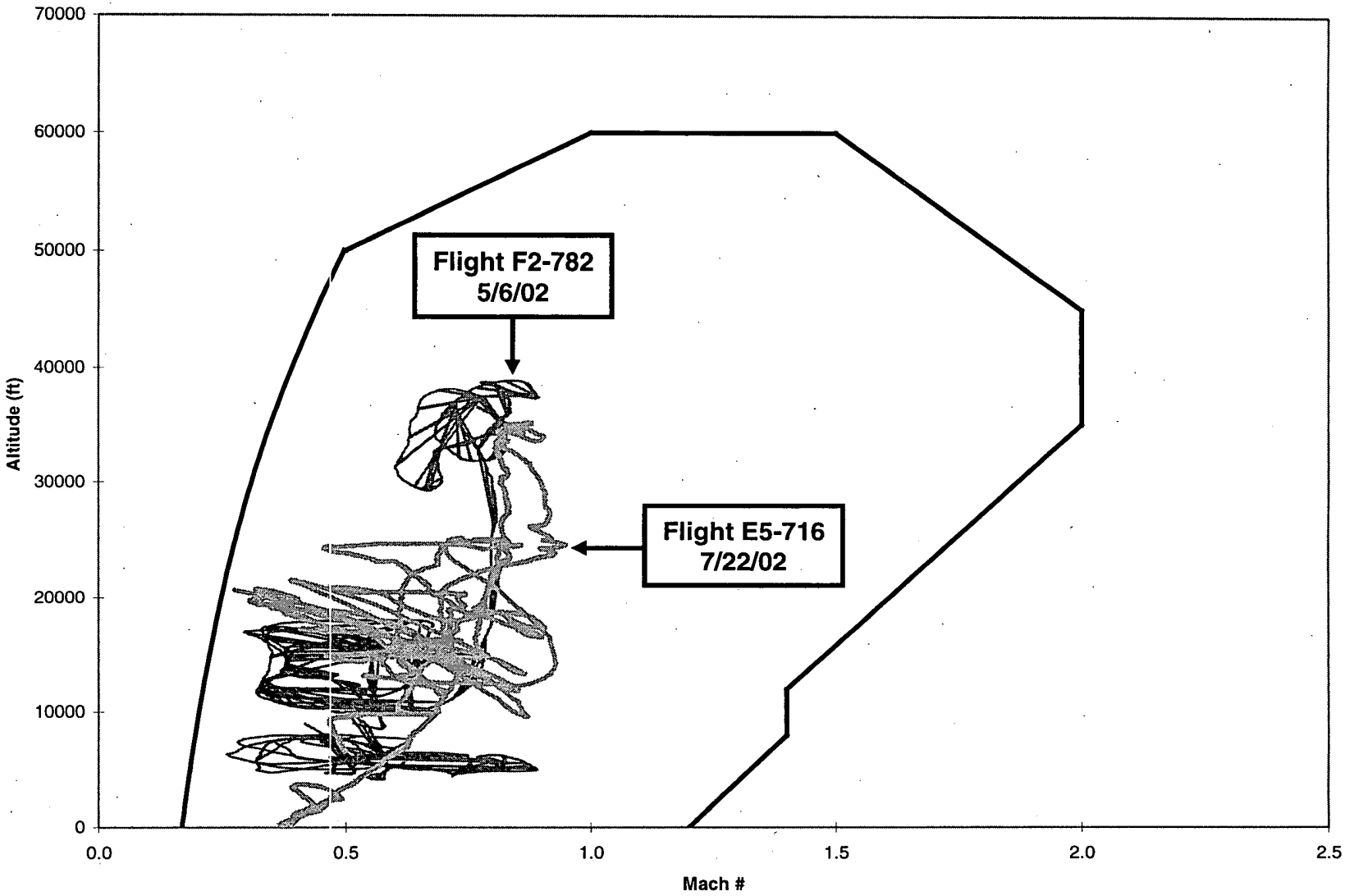

Phase C Demonstrated Maneuver Highlights

BAE SYSTEMS

- **MAX A/B AOA Highlights**
  - 3° < 35K
  - 7° ≥ 35K
- **MIL Power Highlights**
  - 30° AOA
  - -0.8 g's to 6.8 g's
  - ~120 KCAS to 530 KCAS
- **Combat Maneuvers**
  - Aileron Roll
  - Lag Roll
  - High Yo Yo
  - Extension/Pitchback
  - Maximum Performance Break Turn
  - Pushover from Horizontal Scissors
  - Squirrel Cage
  - Simulated Bomb Run

Phase C Flight Test Summary

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No	Date	Alt (Ft)	A/S (KCAS)	Q (psf)	Eject	Safe Separation	Full Deploy	Stable Flight	Continuity		Strength	Op Time	A/B Exp	Max A/B AOA Achieved				Comments
									Electrical	FO				5K	15K	25K	35K	
1		10,500	325	348	Y	Y	Y	Y	59 Min	56 Min	To Sever (64 Min)	56 Min	80 Sec	1°	3°	N/A	7°	
2		10,000	375	457	Y	Scratch	Y	Y	98 Min	96 Min	To Sever (109 Min)	96 Min	20 Sec	2°	N/A	N/A	N/A	
3		10,000	425	604	Y	Scratch	Y	Y	2.5 Min	2.5 Min	To Sever (48 Min)	2.5 Min	10 Sec	1°	N/A	N/A	N/A	Attempted High Risk Test Point First
4		10,700	378	449	Y	Scratch	N	Y	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Reel Count Circuit Failure
5		10,100	374	449	Y	Scratch	Y	Y	77 Min	62 Min	To Sever (77 Min)	62 Min	42 Sec	3°	N/A	N/A	N/A	LOST FO during 5K, 2° AOA A/B Manuever. Electrical Cont maintained throughout.
6		10,200	374	449	Y	Scratch*	Y	Y	68 Min	68 Min	To Sever (68 Min)	68 Min	60 Sec	N/A	3°	N/A	7°	HVS Breakdown prior to 35K test points traced to breakdown in captive carry canister. Entire sytem checked OK post flight.
7		10,000	375	449	Y	Scratch*	Y	Y	9 Min	9 Min	Broke @ 9 Min	9 Min	N/A	N/A	N/A	N/A	N/A	Decoy broke off during >7g Break Turn
8		10,000	374	449	Y	Scratch	Y	Y	110 Min	110 Min	To Sever (110 Min)	110 Min	62 Sec	N/A	N/A	4°	7°	No HVS Data. Entire System Checks OK Post Flight.
9		10,000	375	449	Y	Scratch*	Y	Y	47 Min	47 Min	To Sever (64.5 Min)	47 Min	N/A	N/A	N/A	N/A	N/A	Lost FO and HV During Simulated Bomb Run Dive (45° dive, >530 KCAS)
10		10,000	375	449	Y	Scratch*	Y	Y	51 Min	69 Min	Broke @ 69 Min	51 Min	65 Sec	N/A	N/A	4°	5°	Exceeded Goal Envelope @ 25K. Subsequently lost HV during 35K, 5° AOA A/B maneuver. Towline Broke during 5K, 3° AOA A/B maneuver

* Centerline Tank Installed

Phase C Summary

Eject	Safe Separation	Full Deploy	Stable Flight	Continuity		Strength	Op Time	Total A/B Exp	Max A/B AOA Achieved			
				Electrical	FO				5K	15K	25K	35K
100%	Scratch	90%	100%	89%	89%	89%	56 Min	339 Sec	3°	3°	4°	7°

ALE-55 Canister Ready For DT/OT!

MAX A/B Survivability Summary

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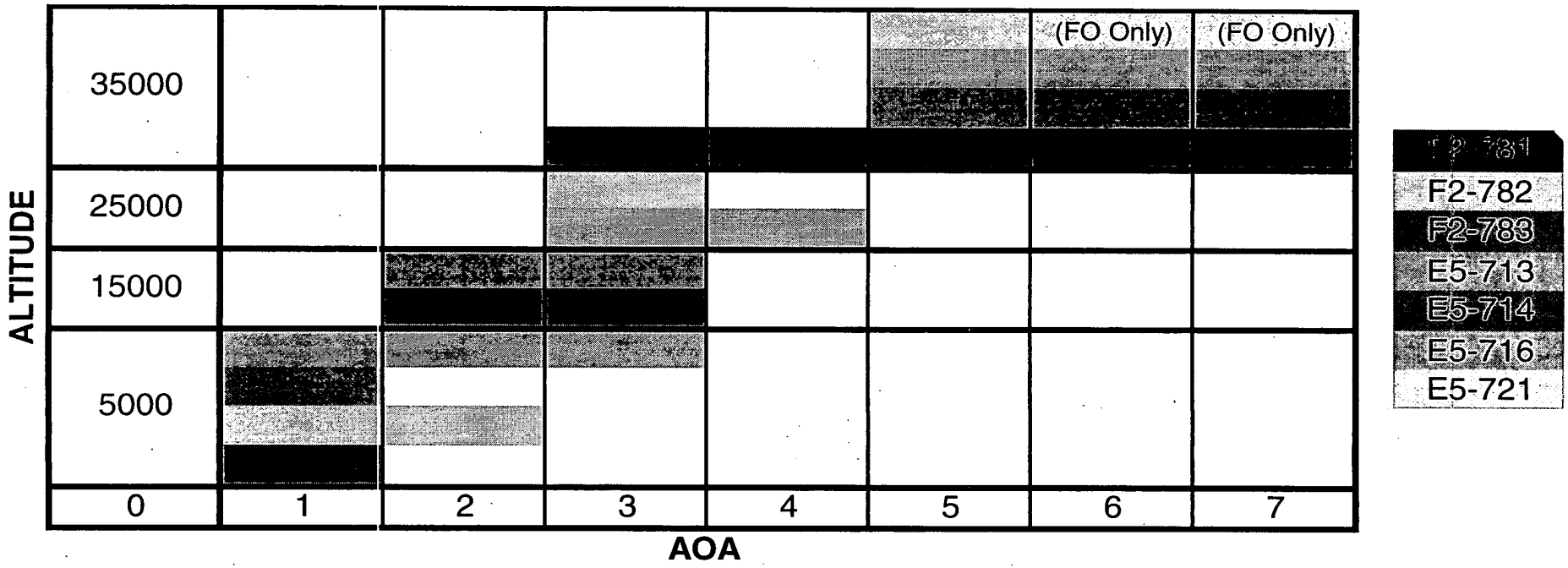


ALE-55 Canister Achieved Phase C A/B Objectives!

BAE SYSTEMS

Post Flight Hardware Analysis

B. Sarantis

Tear Down Analysis Overview

BAE SYSTEMS

Conducted Complete Tear Down Analysis on All Canisters, Decoys and Cables Returned from Phase C Flight Tests

No Evidence of Workmanship Problems Found Which Caused Flight Problems

No Evidence of Thermally Induced Damage to The FO or Conductors

Hardware Summary

BAE SYSTEMS

S/N	Snubber	Flight Info	ALT	KCAS	Q	CL Tank	AB/Alt	Flight Time	FO Time	Elect Time	A/B Time	Canister Info			Decoy Info	Cable Info		
		Plane/Pos						(Min)	(Min)	(Min)	(Sec)	Snubber	Flapper	Brake		Flapper	Standoff	Hot Zone
18	GR	F2 / 3	10.5K	325	348	N	35K, 3,4,5,6,7	64	56	59	80	Normal	Normal	Normal		Normal	One Mark	Good FO/C
							15K, 2,3											
							5k,1 fail FO											
22	GR	F2 / 3	10k	375	457	N	5K, 1, 2	109	96	98	20	Normal	Normal	Normal		Normal	Two Marks	Good FO/C
							FO Pre-A/B											
							HV (Cath) In A/B											
24	GR	F2 / 3	10K	425	604	N	5K, 1, Fail FO/350V	48	2.5	2.5	10	Normal	Normal	Normal		Normal	Offset Marks	Good FO/C
17	GR	E5 / 1	10.7K	378	449	N	N/A	N/A	N/A	N/A	N/A	Normal	Normal	Normal	Lost [1]	N/A	N/A	N/A
30	BAE	E5 / 1	10.1K	374	449	N	5K 3,2,1	77	62	77	42	Normal	Normal	Normal		Normal	One Mark	Good FO/C
							Failed FO only @ 2											
33	BAE	E5 / 1	10.2K	374	449	Y	15K, 2,3	68	68	68	60	Normal	Normal	Normal		Normal	One Mark	Good FO/C
							35K 5,6,7											
29	BAE	E5 / 3	10K	375	449	Y	N/A	9	9	9	N/A	Normal	Normal	Normal	Lost [2]	Normal	One Mark	Good FO/C
35	BAE	E5 / 3	10K	374	449	N	25K, 3,4	110	110	110	62	Normal	Normal	Normal		Normal	One Mark	Good FO/C
							35K, 5,6,7											
34	BAE	E5 / 3	10K	375	449	Y	N/A	64.5	47	47	N/A	Normal	Normal	Normal		Normal	One Mark	Good FO/C
28	BAE	E5 / 3	10K	375	449	Y	25K, 3,4Brkdn	69	69	51	65	TBD [4]	TBD [4]	TBD [4]	Lost [3]		One Mark	N/A
							35K,5,6,7											
							HV (Cath) @ 5											
							5K, 3 Line Broke											

Notes:

1. Reel Count Failure. Signal line was completely unwound and pulled off signal spindle.
2. Decoy lost during maximum perfromance break turn (7 g.)
3. Line broke during 5K, 3° AOA, Max A/B turn
4. Canister inspection not completed. Awaiting return of hardware.

Mass Model Round TDM017

BAE SYSTEMS

- **Flight E5/712**
- **Failed at Launch**
  - Signal Cable Pulled All the Way Out
  - Many Feet of Tow Line Deployed (~30')
  - No Reel Counts Recorded
- **Problem Isolated to Cracked OPTO Coupler Chip on Reel Count CCA**
  - Examination Showed Ceramic Case Was Cracked Prior to Conformal Coating
  - Failure Mode Unique to This Circuit Card
- **Performed Detailed Inspection of Additional CCA's Pulled From Stock**
  - Evaluated 49 CCA's
  - No Cracks Found
- **Corrective Action Initiated**
  - Additional Test Added Post ESS to Test OPTO Coupler Operation
    - ✓ 100% Screening for All Mass Model and FOTD Rounds

Failure Mode Identified - Corrective Action Implemented

Mass Model Round TDM033

BAE SYSTEMS

- **Flight E5/714**
- **HVS Data Indicated Cathode Arcing While Climbing to 35K Feet**
  - Failure Mode Never Encountered in Prior Flight Test
- **Canister, Decoy and Cable Were Extensively Tested To Re-Create/Identify the Failure**
  - Testing Conducted with High Voltage at Altitudes to 35K
    - ⇒ ***No Evidence of Arcing Seen***
- **Conducted Evaluation of HVS Box (S/N 1) and Two Captive Carry Canisters (S/N 31 and 35) Used During Flight Testing**
  - Testing Conducted with High Voltage at Altitudes to 60K
    - ✓ HVS Box and Canister S/N 31 Performance Normal
  - Canister S/N 35 Exhibited Intermittent Arcing at 35K and Full Breakdown at 40K Feet
    - ✓ Further Inspection Revealed Damage to the Rubber Seal of the Vk Contact
      - ⇒ Connector Will Be Replaced Prior to FOTD AUR Flight
- **Concluded That Recorded Cathode Failure Was Due to Captive Carry Canister S/N 31 and NOT TDM033**

Evidence Indicates Flight E5/714 (7/12/02) Fully Successful

Mass Model Round TDM029

BAE SYSTEMS

Flight E5/715

Decoy Separated During Maximum Performance Break Turn

- ~7 g's

Chase Reported Line Separation Immediately In Front of Decoy

- Confirmed With Post Flight Review of Chase Video
- Confirmed When Line Was Returned
  - ✓ Examination Showed Loose Areas and Tightly Wound Areas

Examination of Canister

- No Physical Evidence to Explain Loose Line at Deploy
- Pull Test Data Pre and Post Flight Indicated No Anomalies

Passed Same Maximum Performance Break Turn Several Times In Later Flights

No Additional Analysis Planned

Root Cause Unknown - No Corrective Action Planned

Mass Model Round TDM035

BAE SYSTEMS

- **Flight E5/716**

HVS Box Prematurely Started

– Did Not Capture HV Data for Last Hour of Flight

Canister, Decoy and Cable Were Extensively Tested and Evaluated

– Testing Conducted with High Voltage at Altitudes to 35K

⇒ ***No Evidence of Arcing Seen***

– Physical Examination of the Returned Cable Showed No Evidence of Abnormal Wear or Twisting Seen in Other Failures

Concluded That TDM035 Maintained Continuity Throughout Flight

Evidence Indicates Flight E5/716 (7/22/02) Fully Successful

Mass Model Round TDM028

BAE SYSTEMS

Flight E5/721

- **HV Cathode Short @ 35K, 5° AOA A/B Maneuver**
  - Post Flight Review of Data Indicates Significant Thermal Stress to Line at 25K, 4 deg AOA A/B Maneuver
    - ✓ Beyond Goal Envelope
  - Overstress Condition Resulted In Subsequent Short @ 35K
- **Tow/Signal Line Failure @ 5K, 3° AOA A/B Maneuver**
  - Cathode Short @ 35K Resulted In 5 KV Arcing Throughout Remainder of Flight
    - ✓ Recovered Cable Shows Evidence of Exposed Wires and Significant Arcing
  - Continuous Arcing Damaged Tow and Signal Jacket
  - Tow and Signal Line Ultimately Failed When Stressed During the 5K A/B Maneuver

Evidence Indicates Flight E5/721 (8/14/02) Failure Result of Exceeding Envelope Goal

Mass Model Rounds TDM018, 022, 024, 030 and 034

BAE SYSTEMS

- **Flights F2/781 F2/782 F2/783 E5/713 - , E5/717**

- **All Experienced Mechanical Failures Of The Signal Line**

  Detailed Analysis of the Units Revealed Several Similarities

  – All Had Good FO and Continuity From the Canister Through the Hot Zone

  ✓ ***Indicates Failure Not Thermally Induced***

  – All Had Good FO and Continuity in the Canister

  – S/N 18, 24 and 34 Had Good FO and Continuity in the Decoy

  ✓ Unable to Assess S/N 22 and 30 Since The Units Sustained Mechanical Damage to the Termination at Landing

  – All Showed Area of High Twisting Past the Hot Zone

- **Preliminary Failure Mode Attributed to Heavy Twisting Of The Signal Line**

Failure Mode Identified - Further Analysis Required

EXHIBIT "C"

BAE SYSTEMS

Post Flight Tow/Signal Line Analysis

Dr. J. Dion

Exhibit "C"

Post Flight Cable Analysis Process

BAE SYSTEMS

- **Line Layout Inspection Process**
  - Untangle
  - Layout
  - Optical Inspection (to 50X)
  - Digital Photos
- **Continuity Evaluation**
  - Electrical & Fiber
- **High Pot Testing**
  - Standard Temperature and Pressure
  - Altitude Chamber

TDM033 Assessment

BAE SYSTEMS

Towline survived flight test points

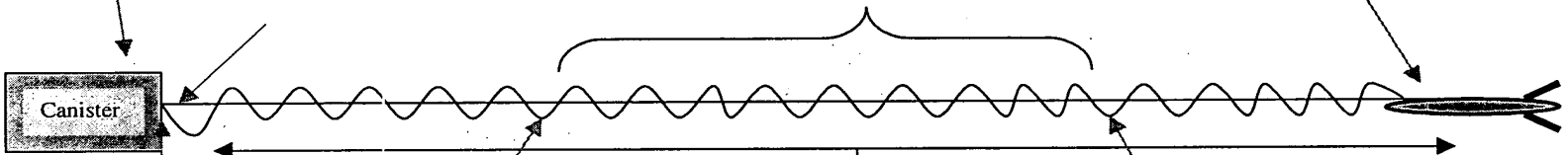
Mission Data
- Flight E5/714
- 7/12/02
- A/B Maneuvers

No HV Shorts on the spool
High Potted…wires visually examined. No Arc spots on Spool

~11-12 feet
Mild "goal post" wear

FO Break(s) from:
- Recoil / Landing / Handling

No Arcing on egress hole



- Flapper damage
  - ~8.5" from cut end
    ~ 1-2 ends abraded
  - ~ 0.5 ends cut at 2.5" from cut end

100 ft. Tap point
- FO continuous from canister

100 ft. Tap point
- FO continuous from decoy

- Electric continuity throughout (no shorts)
- No HV shorts throughout
- Visual of Decoy and spool line for arcing, negative
- No A/B heat induced damage visible
- Zylon Color Normal
- Minor "Pooching"

Representative of Fully Successful Flight

TDM035 Assessment

BAE SYSTEMS

Towline apparently survived flight test

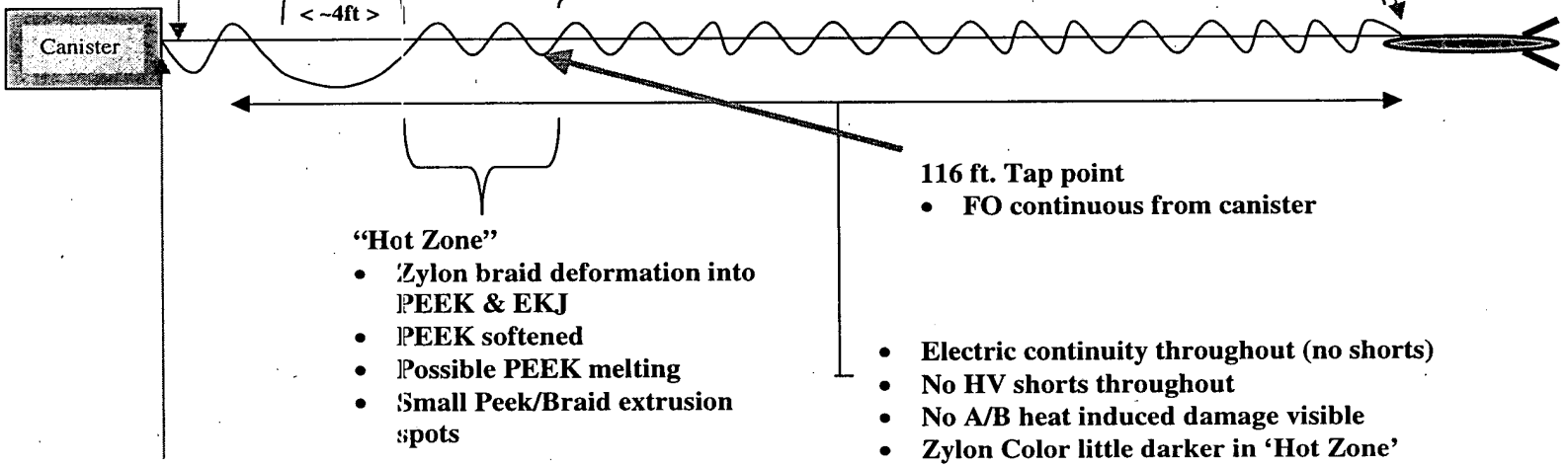
Mission Data
Flight E5/716
•7/22/02
•Combat Maneuvers
•A/B Maneuvers

~11-12 feet
Mild "goal post" wear

~20-24ft from Can
- Uncoiled Signal from Tow

FO Break(s) from:
- Recoil / Landing / Handling

No Arcing on egress hole



"Hot Zone"
- Zylon braid deformation into PEEK & EKJ
- PEEK softened
- Possible PEEK melting
- Small Peek/Braid extrusion spots

116 ft. Tap point
- FO continuous from canister

- Electric continuity throughout (no shorts)
- No HV shorts throughout
- No A/B heat induced damage visible
- Zylon Color little darker in 'Hot Zone'
- Minor "Pooching"

Flapper damage (Tow & Signal)
- ~5" from cut end
  ~ 1-2 ends abraded (both) & cut on tow
- ~ 0.5" ends cut at 2.5"from cut end on tow
  & abraded on both

Representative of Fully Successful Flight

TDM030 Assessment

BAE SYSTEMS

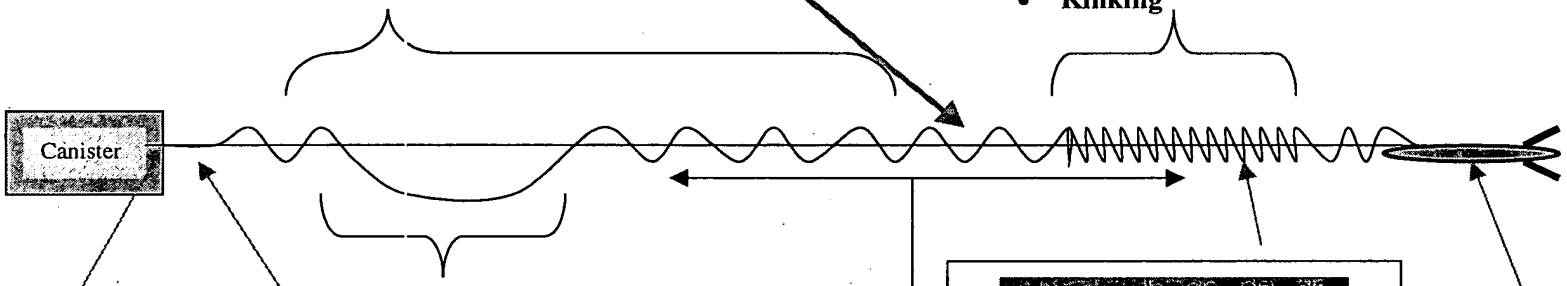
* Passed 5k 3° AOA A/B; Fiber Optic failed during 2° AOA A/B, HV passed 3, 2, 1 AOA

~40-90 ft. from canister:
- Discoloration of Tow & Signal
- Minor abrasion
- Pooching

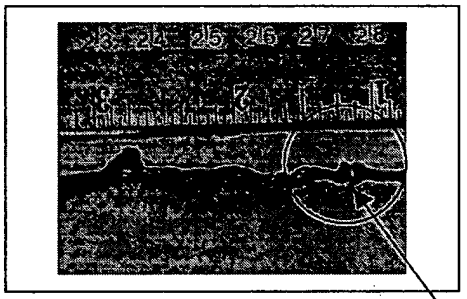
100-ft. tap point from can
- Fiber Optic continuous

35-55 ft from decoy
- Severe Signal line pitch/twist (fiber failure region)
- Gore's "wire" pitch increased heavily
- PEEK Distortion
- Kinking

Mission Data
Flight E5/713
•7/11/02
•Combat Maneuvers
•A/B Maneuvers



~52-60 ft from canister:
- Uncoiled Signal from Tow
- Zylon braid deformation into PEEK & EKJ
- PEEK softened
- Possible PEEK melting



Decoy Sustained Damage During Landing

- Flapper damage
  - ~8.5" from cut end, ~ 1-2 ends abraded
  - ~ 0.5 ends cut at 2.5"from cut end

FIBER FAILURE

~11-12 feet
Mild "goal post" wear

- Light Abrasion of Signal Line Through-out
- Zylon Color Normal
- No heat induced damage visible
- Electric continuity throughout (No Shorting)

Representative of Heavy Twist Failure

Cable Inspection Summary

BAE SYSTEMS

	IN FLIGHT CONDITIONS				POST FLIGHT CONDITIONS		
Flight	Snubber	Plume A / B	F.O. Continuity	Electric Continuity	"Hot Zone" Fiber	"Hot Zone" Electrical	Comments
TDM018	G.R.	Yes	Lost @ 5k A/B	Yes	Continuity	Continuity No shorts @ 5kV	Probable failure mode: High twisting on signal line.
TDM022	G.R.	No	Lost prior to 5k A/B	lost prior to 5k A/B	Continuity	Continuity No shorts @ 5kV	Probable failure mode: High twisting on signal line. Survived MIL Power testing to ~30° AOA. 2 wear areas seen.
TDM024	G.R.	Yes	Lost @ 5k A/B	lost @ 5k A/B	Continuity	Continuity No shorts @ 5kV	Probable failure mode: High twisting on signal line. Very short flight. Signal line wear pattern offset at stand-off.
TDM017	NA	NA	NA	NA	NA	NA	NA
TDM030	BAE	Yes	Lost @ 5k AB	Yes	Continuity	Continuity No shorts	Probable failure mode: High twisting on signal line.
TDM033	BAE	Yes	Yes	Yes	Continuity	Continuity No shorts @ 5kV	No shorts @ 5kV throughout Note: Line "pristine"...
TDM029	BAE	No	Lost Decoy	Lost Decoy	Continuity	Continuity No shorts	Probable failure mode: Looseness of Line and Twisting
TDM035	BAE	Yes	Yes	Most Likely	Continuity	Continuity No shorts @ 5kV	No shorts @ 5kV throughout. HVS Data logger off during A/B
TDM034	BAE	No	Lost @ 45° dive	Lost @ 45° dive	Continuity	Continuity No shorts	Probable failure mode: High twisting on signal line.
TDM028	BAE	Yes	Lost @ 5k A/B	HV high @ 25k A/B HV lost @ 35k A/B	Continuity to 30 ft.	Continuity No shorts to 30 ft.	25k A/B 4° test pt. damaged the EKJ, resulting in 35k A/B failure. 5 kV arcing damage weakened line resulting in line breakage

Cable Guide Damage Summary

BAE SYSTEMS

- **Cable Guide**
  - Rubber Worn Through to Metal All Flights
    - ✓ Wear Patch Positioned the Same on All Flights
      - ⇒ Typical Damage (No Electrical / Optical Problems)
      - ⇒ Off Center to the Left Looking Out Though the Rear Can
- **Lines @ Cable Guide**
  - Tow: Some Fiber Ends Cut Though Due to Flapper
    - ✓ Damage Occurs on 1 Side (All Flights)
      - ⇒ Implies No Twisting/Rolling
  - Signal: Fibers Frayed at Varying Degrees
    - ✓ Conductors and FO Kinked Slightly

Cable Guide Wear Normal

Goal Post Damage Summary

BAE SYSTEMS

Tow

- Light Abrasion on Cable
- No Broken Fiber Ends

Signal Line Jacket

- Very Light Abrasion
- 2 Visible Wear Areas on TDM022 (Greene Rubber Snubber)
- Wear Pattern Offset on TDM024 (Greene Rubber Snubber)
- 1 Consistent Wear Area On All BAE Snubber
  - ✓ No Evidence of Excess Signal Line

Goal Post Wear Normal/BAE Snubber Provides Improvement

Plume Survivability Highlights

BAE SYSTEMS

- **Max A/B**
  - F.O. Continuity Maintained Throughout Hot Section
  - 4 Mil EKJ Leakage Seen at Various Test Points
    - ✓ All Leakage Within Goal Envelope Recoverable
  - Post Flight Analysis (Continuity, HV & Microscopy) Shows No Permanent Degradation in EKJ, F.O./ Coatings
    - ✓ Polyimide Buffer Pristine

MIL Power

- F.O. Continuity & No Leakage at All Mil Power Test Points
  - ✓ to 30° AOA

Excellent Thermal Performance!

High Twist Mechanical Failure Theory

BAE SYSTEMS

- **Failure Mode: Signal Line Slip Over the Tow Line**

  Effects

  – Signal Line Slip Results In Regions of High Twist

  ✓ Twisting (Torsion Stress) Adds to the Tensile Stresses and Eventually Dominates

  ⇒ FO More Sensitive to Twisting

  ⇒ Local EKJ Thinning Can Create HV Arcs

  – Signal Line Slip Can Also Form Regions of Line Separation

- **Root Cause/Corrective Action Has Not Been Determined**

  – Further Analysis/Testing Required

BAE SYSTEMS

Conclusions and Recommendations

B. Sarantis

Conclusions

BAE SYSTEMS

System Performance Exceeded Thermal Expectations for Phase C

- F.O. Survives Thermal Plume Conditions Tested
  - ✓ Fiber More Robust Than Dielectric
- 4 Mil EKJ Survives Thermal Plume Conditions Tested Within Goal Envelope
- Signal Line Jacket Hot Section Good From Plume Perspective
  - ✓ 6K Denier through 1st 100'
- Towline More Than Adequate

Signal Line Slip Improved With BAE Snubber

Mechanical Failures Due to Heavy Twisting of Line

- FO Breaks
- Opens / Arcing
- Line Fracture &/or Decoy Separation

Separation Performance Marginal

- Surface Scratches > 350 KCAS
- No Damage to Mass Model Decoy

Recommendations

BAE SYSTEMS

Proceed to Envelope Expansion Testing

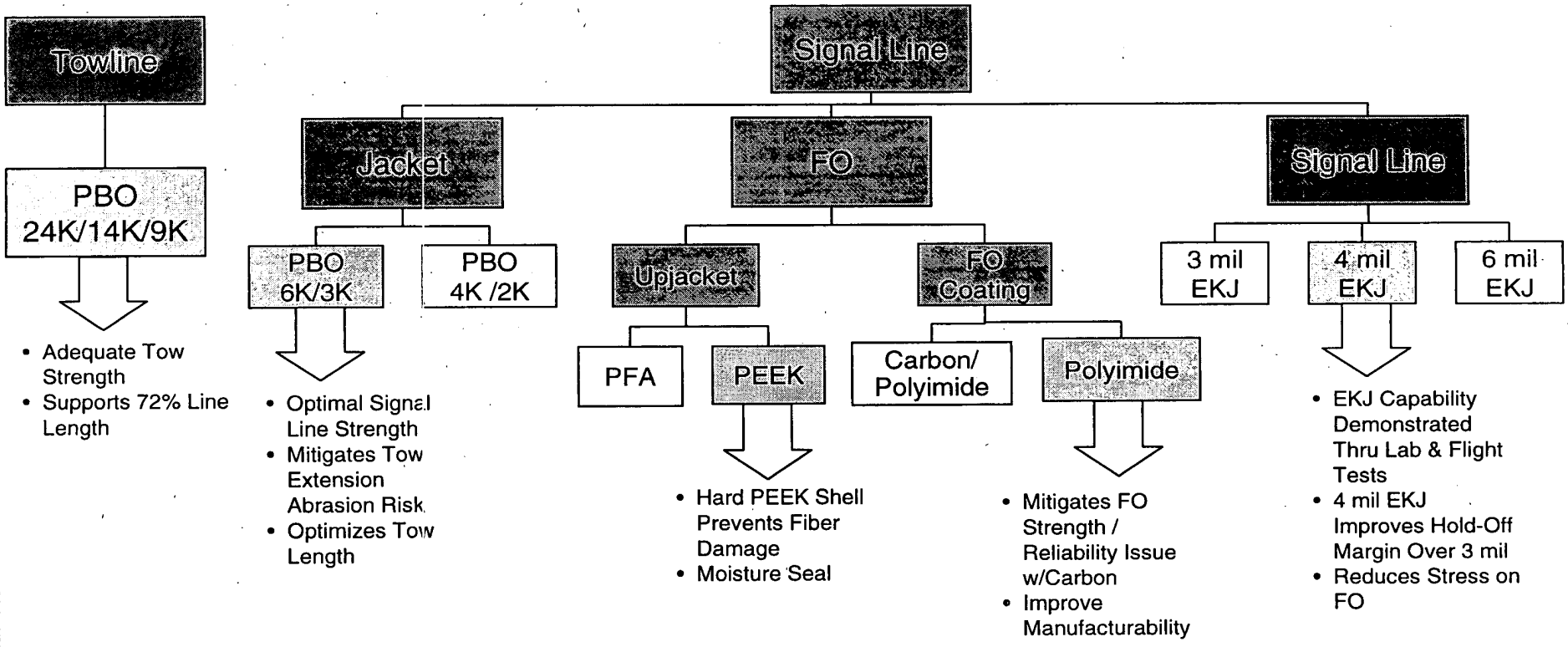
- **Determine Root Cause and Corrective Action for Observed Local Line Twisting**
  - Develop an Analytical Understanding and Augment With Experiments
    - ✓ Laboratory Testing Will Supplement Analysis to Promote Better Understanding of Phenomena
    - ✓ Experiments Will Be Designed Specifically to Address Flight Observations and Analysis Results
      - ⇒ Further Dedicated Corrective Action Testing Will Be Performed
  - Sufficient Funds Remain To Accomplish Root Cause Investigation
    - ✓ Contract Extension Required
  - Incorporate Corrective Action In Future Product Improvements

BAE SYSTEMS

Back-Up

Downselected Tow/Signal Line Configuration

BAE SYSTEMS



Supports 58% Deployment Length

Brake Control Response Reference

BAE SYSTEMS

Curve definitions are as follows:

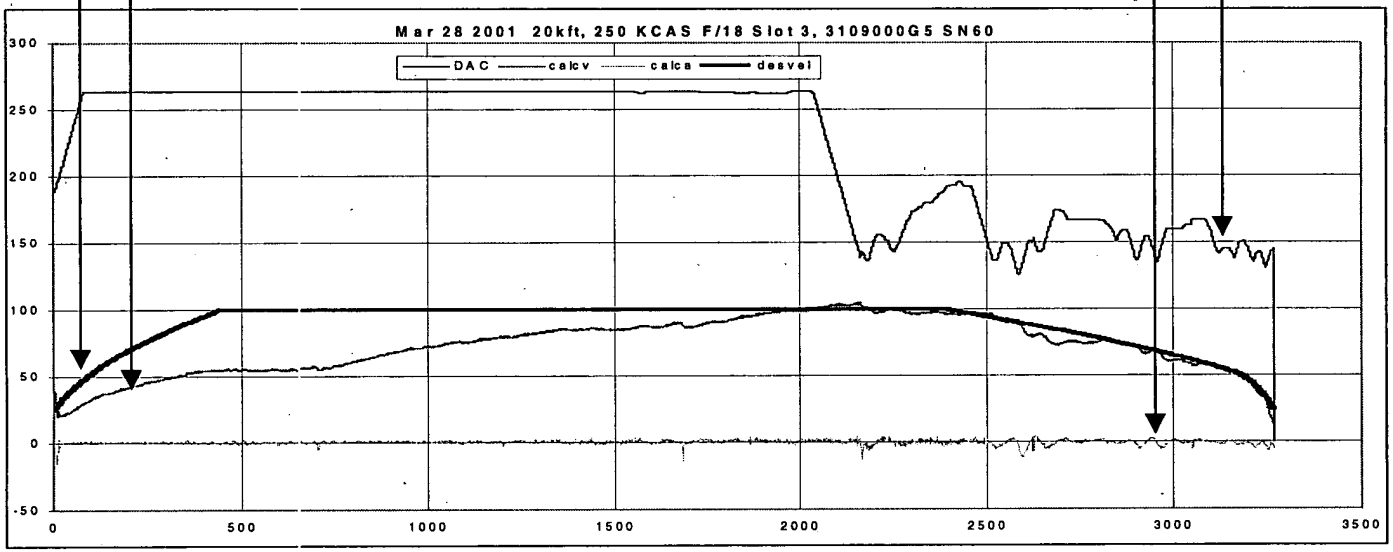
Black - Desired deployment velocity

Magenta - Actual deployment velocity

Blue - DAC, a measure of current supplied to the brake.

- High DAC=low brake force and vice versa
  - 264 = No brake force
  - 0 = Maximum brake force

Red - Acceleration profile of spool during deployment

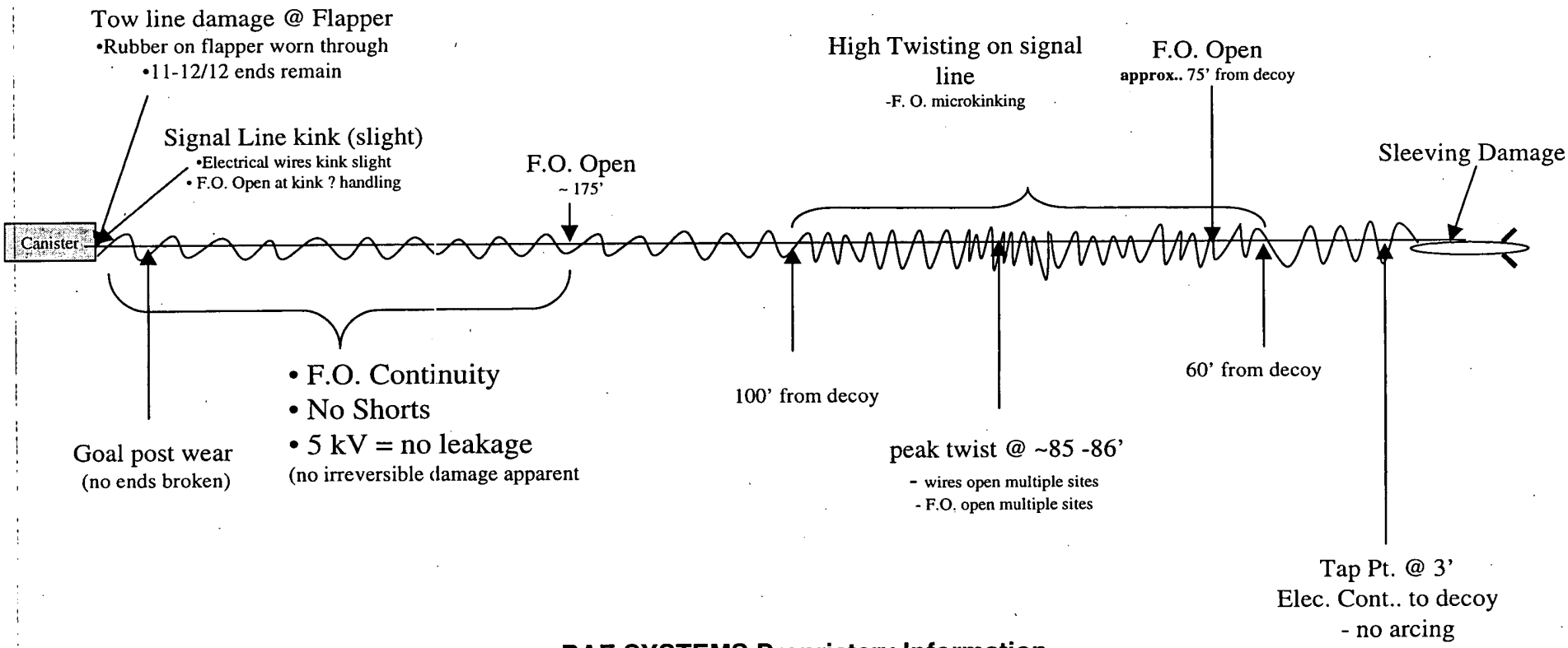


TDM018 Assessment

BAE SYSTEMS

Survived 35K, 15K A/B test pts.
FO lost: 5kft @ 1st Test pt. in A/B
Passed HV @ 1 AOA A/B

Total Time:
- F.O. open: 54 min.
- 350Vopen: 59 min.
- Intermittent shorts: 59 + min.
- Flight duration: 64 min.

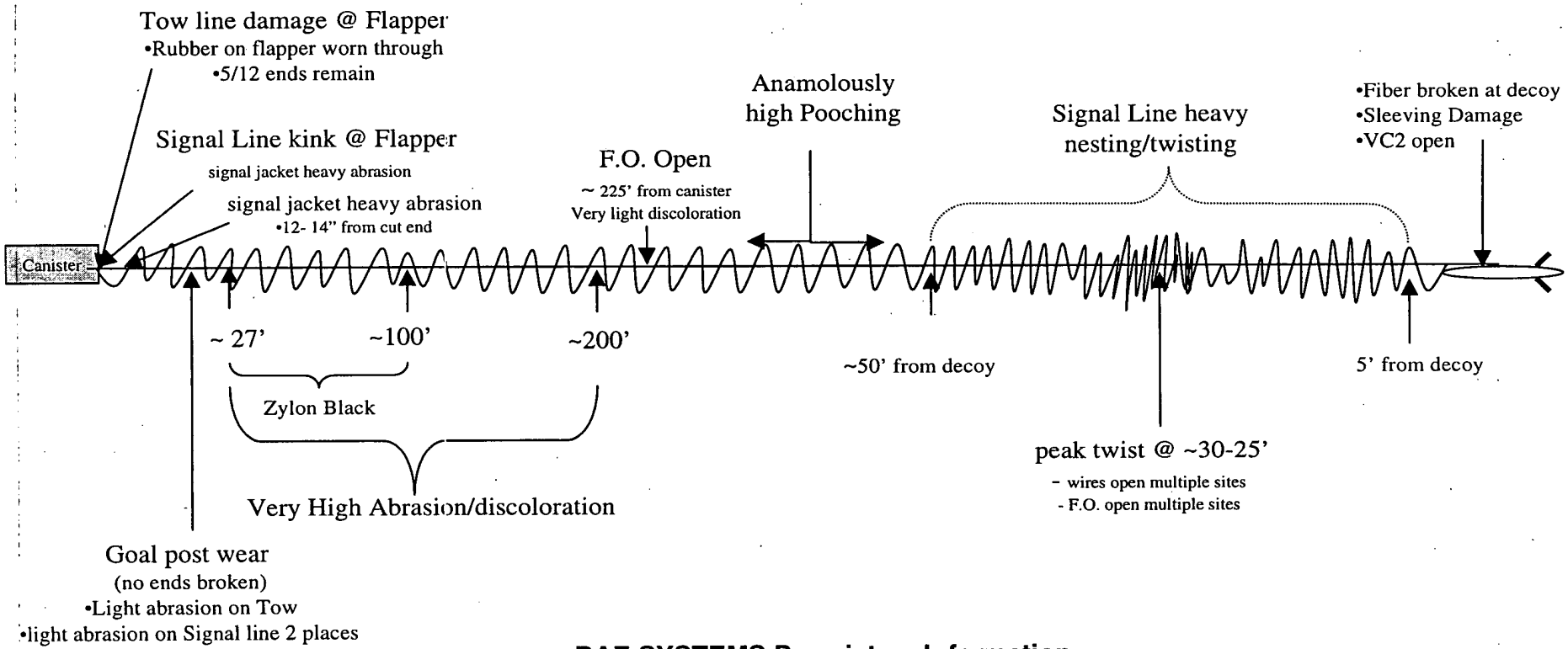


TDM022 Assessment

BAE SYSTEMS

Survived Mil Power testing to very high AOA
FO lost @: 5kft setting up for 1st A/B test pt.

Total Time:
- F.O. open: 96 min.
- Vk short to 350: 98min.
- Flight duration: 109 min.

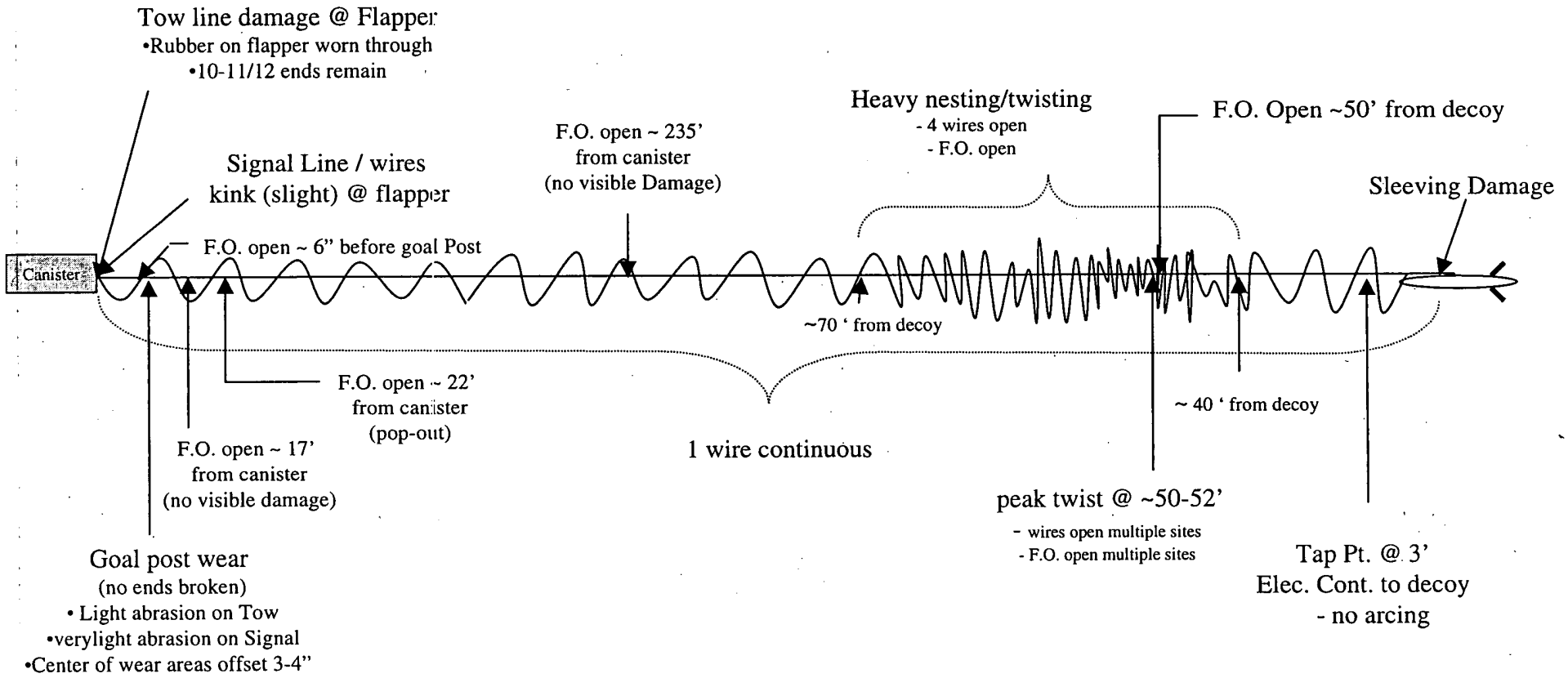


TDM024 Assessment

BAE SYSTEMS

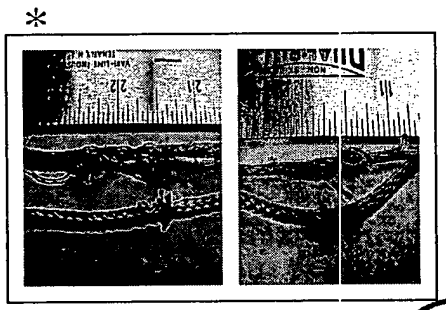
FO lost @: 5kft 8 seconds into A/B at 1st test point

Total Time:
- •F.O. open: 2.5 min.
- •350Vopen: 2.6min.
- •Flight duration.:47 min.



TDM028 Assessment

BAE SYSTEMS



Note: There are no additional Flapper marks to support issue of slippage. Furthermore, 19-ft mark lines up with "turkey fins" on F-18.

~ 23 ft tap pt.
- Fiber Optic Continuity
- ******* Electric continuity (No Shorting)

30 ft end of tow
28 ft end of signal line
- No decoy
- No line

Canister

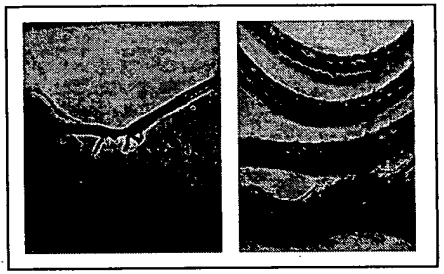
*Flapper damages (Signal)
- ~ 5" from cut end,
- ~ (9-10)/20 ends abraded/cut
- ~ 1.5 ends cut at 2.5" from cut end

Tow
- ~ 5" from cut end,
- ~ 4 - 5 ends abraded
- ~ 1.5 ends cut at 2.5" from cut end

Goal Post Damage (signal and tow)
- ~ 12 ft
  - Mild "goal post" wear
- ~ 19 ft (X-ray TBD)
  - Mild "goal post" wear (tow)
  - * Heavy abrasion on signal

** ~ 21 ft from can
- Excessive Arcing of wires
- 3 Wires open
- Protruding from jacket
- Based on electrical data…
  - Probable post damage. I.e. after line broke
- Insulation burned in 3mm from open on 2 wires

** Heavy burn on Zylon tow

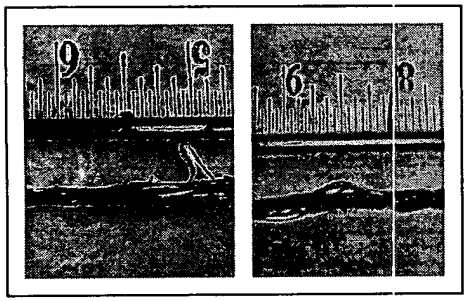


General Condition of line:
- Rest of tow & signal in good shape
- Normal pitch
- Zylon "impression" in PEEK and EKJ
  - Last 5-7 ft

TDM034 Assessment

BAE SYSTEMS

*



~80-90 ft. from canister:
- Uncoiled signal from tow
- * Abrasion (heaviest on cable)
- * Signal Zylon "spread-out"
- "Pooching"

65-105 ft from decoy
- Severe Signal line pitch/twist
- Gore's "wire" pitch increased heavily
- ** Heaviest @ 100-105ft
- PEEK Distortion
- Kinking

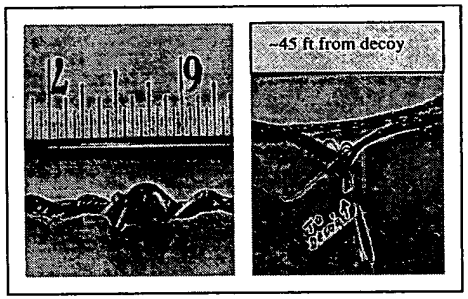
Decoy severed @ ~24 inches

Canister

~1 ft

~2-3 ft

**



~40-55 ft from canister:
- Uncoiled Signal from Tow
- Loose wires ("Pooching")
- Minor abrasion

~11-12 feet
Mild "goal post" wear

~100 ft tap
- Fiber Optic Continuity

- Flapper damage (tow)
  - ~ 5" from cut end, ~ 4 - 5 ends abraded
  - ~ 1.5 ends cut at 2.5" from cut end
  - Signal jacket mild wear
    - details lost due to handling / snapback..."

Between 105 ft from decoy & 90 ft from decoy, Cable & tow "normal"
- Light Abrasion of Signal Line Through-out
- Zylon Color Normal

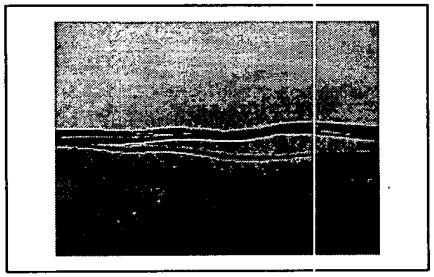
******* Electric continuity throughout (No Shorting)

TDM029 Assessment

BAE SYSTEMS

Flight 7-16-02

TDM 029



- Flapper damage
  - ~5" from cut end
  - ~ 1-2 ends abraded
  - ~ 0.5 ends cut at 2.5" from cut end

~80ft. From canister, Heavy twisting:

- Signal
- Pooching
- Gore pitch decreased to 1 twists/inch
- Heavy abrasion

100-ft. tap point from can

- Fiber Optic continuous

25-30 ft Signal cable

- Gore's "wire" pitch increased
- Heavy Peek distortion
- Zylon distorted tows

~5ft

Canister

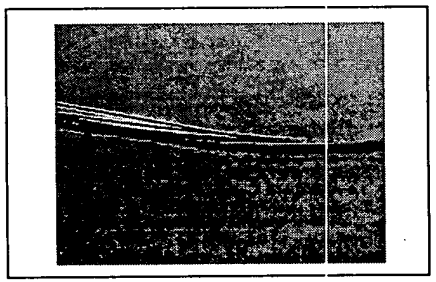
~11-12 feet
Mild "goal post" wear

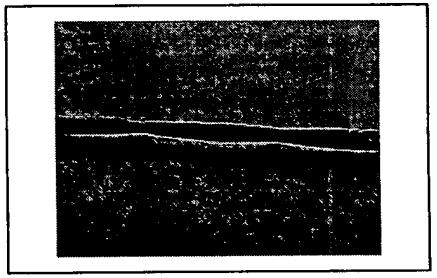
~6.5 ft. of Signal Line Missing

- Assorted Knotting of Signal on Towline
  - Knot contains finger green marks

Signal pitch around tow very loose

- Light Abrasion of Signal Line Through-out
- Zylon Color Normal
- No heat induced damage visible
- Electric continuity throughout (except 14 inches from decoy end)





High Twist Failure Action Plan

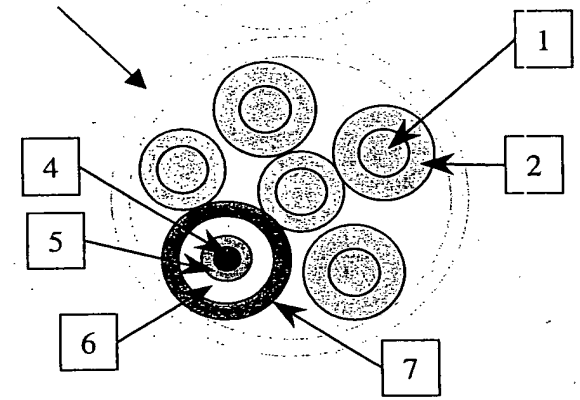
BAE SYSTEMS

- **Re-look at Flight Test Data Using Parameter Fusion to Perform Trend Analysis**
  - Merge Calculated System States for Flight Conditions of Interest
    - ✓ Includes: Tension, Droop, Decoy AOA, Fin Sweep, Etc.
      - ⇒ Data Feeds Subsequent Actions
- **Analyze Flight Conditions Where Anomalies Occur**
  - Calculate Line Vibration Frequencies and Amplitudes
- **Design Experiments to Emulate Flight Conditions / Results.**
  - Vary Key Round Parameters, E.G., Snubber Back Tension, Cable Capstan Effect, Etc.
    - ✓ Experiment Will Be Utilized to Assess Relative Merit of Corrective Actions
  - Utilize Existing Modeling Capability, 6 DOF, and Current Laboratory Facilities.
    - ✓ Conduct Modified Experiment, Similar to B-1B Fixture, Will Be Utilized to Assess Improvements
- **Develop Solution to Problem Within Framework of Existing Variable Set**
  - Example: Increase Snubber Back Tension, Modify Tow Cable Coating Locally to Improve Adhesion, Modify Signal Cable Elements to Change Stiffness / Memory, Etc.
- **Validate Relative Change to System Performance Using Experiment Previously Designed**

Selected Configuration – Towline Upgrade

BAE SYSTEMS

0.052" @ 12K Denier
0.040" @ 9K Denier



Baseline Cable System

Tow	
Baseline	**Upgrade**
2 Stage	3 Stage
12k / 9k denier	24k / 12k / 9k denier

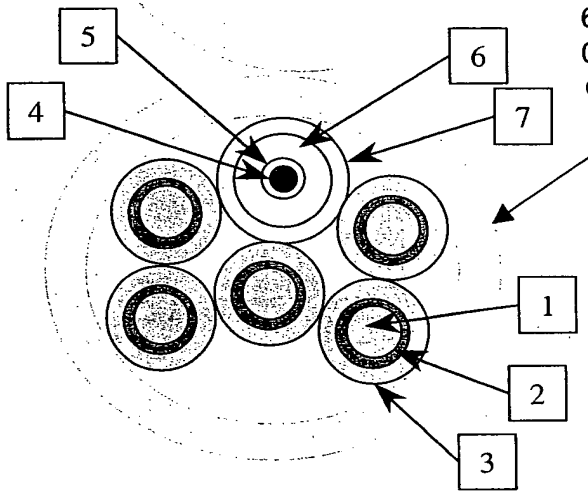
Signal - Jacket	
Baseline	**Upgrade**
2k denier	6k / 3k denier

Signal - Conductors		
	Baseline	**Upgrade**
1	**32 Ga copper**	**32 Ga copper**
2	**MIL-ENE** 0.002" / 0.003"	**PTFE** 0.0005"
3	**N/A**	**EKJ** 0.004"

Signal - Optics		
	Baseline	**Upgrade**
4	**Glass**	**Glass**
5	**Acrylate** 245 microns	**Polyimide** 152 microns
6	**PTFE** 0.003"	**PTFE** 0.003"
7	**FEP** 600 micron OD	**PEEK** 600 micron OD

0.072" @ 24k Denier

0.062" @ 6K Denier 0050" @ 3K Denier

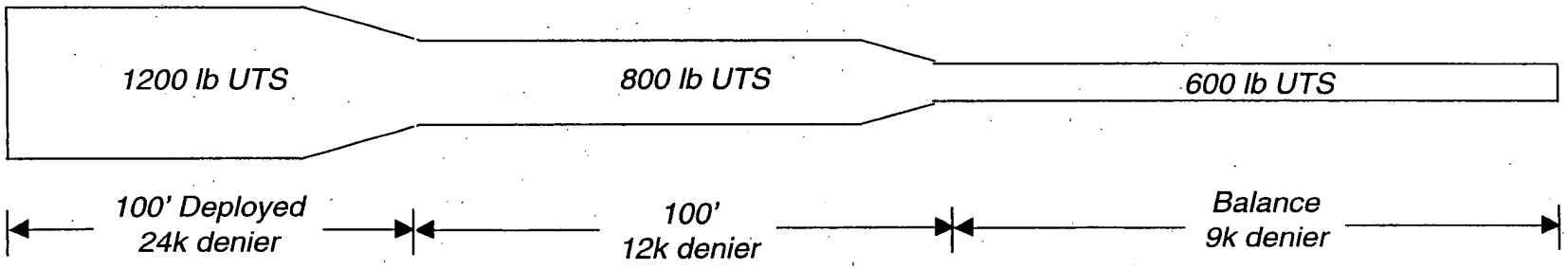


Configuration for Flights

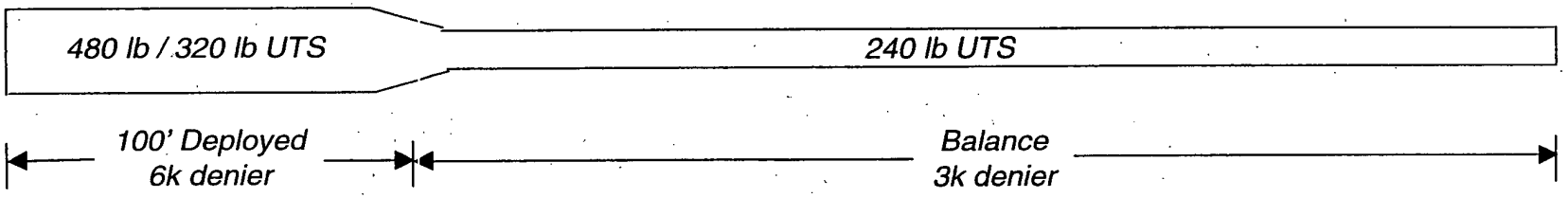
Selected Configuration – Towline Upgrade

BAE SYSTEMS

Tow Cable **Flights**



Signal Cable Jacket



- Packaged length
  - Tow 72% spec
  - Signal 61% spec
- Deploy Length = 58% spec

- Worst Case Margin (@58% spec)
  - Tow: 3.3
  - Signal: 3.6
  - Glass better than 200%

BAE SYSTEMS

Future Optimization Paths

Length Optimization Areas

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Redesign Canister to Optimize cable

– Repartition signal and tow spindle sizes

  • Bounded by other canister constraints

Optimize Tow Cable Diameter

Change Insulation Material

Reduce Fiber Optic Coatings

• Install Moisture Barrier

– May allow thinning of insulation

Rerouting of 350V and ground to tow cable

Anomolous Leakage Current

BAE SYSTEMS

- There is a general relationship between leakage and high temp
  - Leakage ~ exp (T)

  Phase A testing showed ~ mA's of leakage through the dielectric

  Lab testing at expected temperatures results in μA of leakage

  Potential reasons for the discrepancy
  - Temperature incorrect
  - Length effect
  - Environment
    - Water
    - Free Radicals
    - UV Photons

Lab Testing EKJ Insulation

BAE SYSTEMS

Leakage linear with length

Water however produced a significant increase in leakage and a decrease in breakdown strength

- Free Radicals and/or UV Photons could also reduce breakdown strength

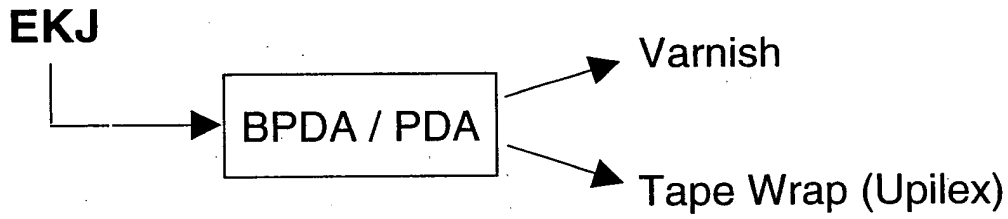
- Water effect also consistent with NRL's data

- Potential Solution:
  - Add plume gas barrier by wrapping metalized film between the Zylon jacket and the wires/fiber optic section

If NRL's temperatures are true, a plume gas barrier will allow for reduced wire insulation thickness

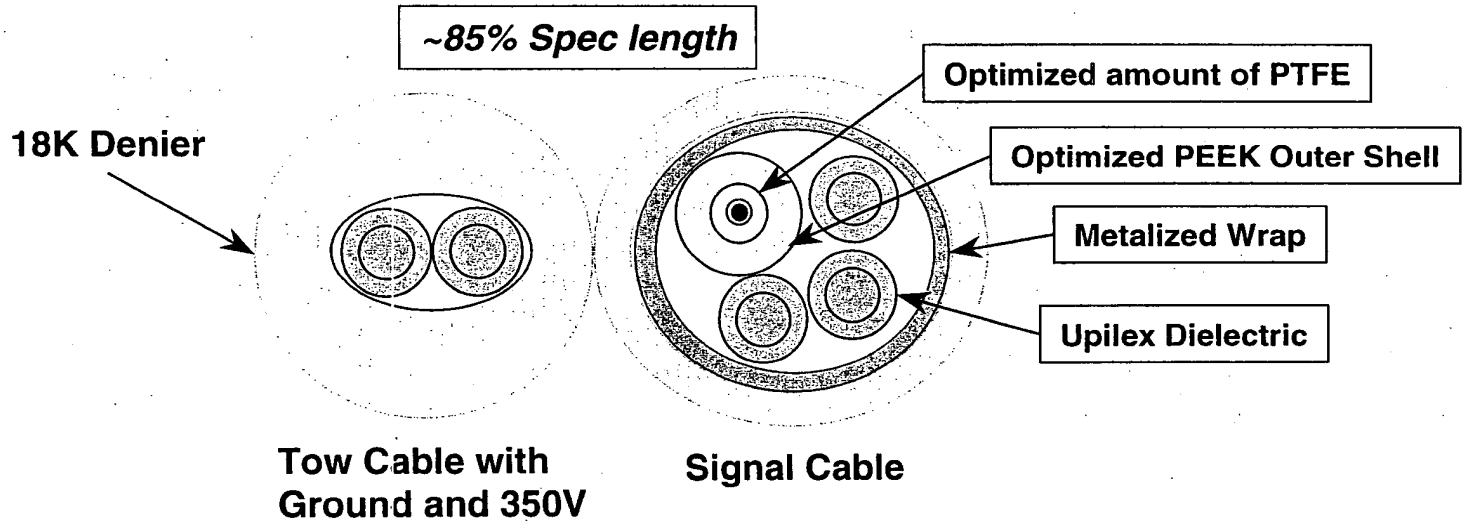
Dielectric Roadmap

BAE SYSTEMS



- "Upilex-S" varnish at 1-3 mils (recently coated on a 36 Ga wire)
  - 1 mil of "Upilex-S" varnish is equivalent to ~3 mils of EKJ
  - 5kV up to ~450C
- "Upilex-S" varnish also being developed through Navy SBIR contract with local companies

Potential Concept to Grow Length/AB AOA



Tow line braid has dead space

– Adding two conductors/36-34 AWG reduction allows no/limited diameter growth

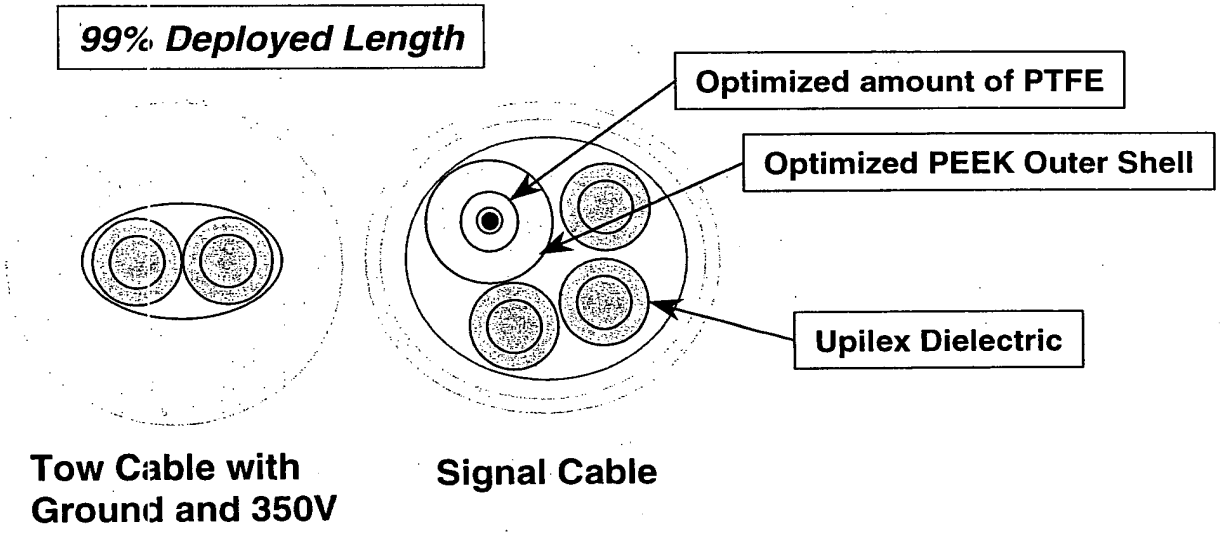
Added benefit increases plume exposure

– 5kV difference is now dissipated over 0.020" to 0.030"
– Signal jacket 2.5kV

Lab testing exceeds ALE-50 performance. Breakdown 0.003" EKJ increased to 550C

Potential Concept to Grow Baseline Length

BAE SYSTEMS



- Tow line braid has dead space
  - Adding two conductors/36-34 AWG reduction allows no/limited diameter growth
- Signal jacket diameter reduced from 0.045" → 0.032"
  - Drag loads reduced

  Signal jacket 2.5kV allows insulation reduction
- Estimated deployable length ↑ from 90% to 99% with canister repartitioning

Summary

BAE SYSTEMS

Substantial improvements made to the tow/signal cable endurance

– Survived 200 seconds of A/B exposure

Flight testing of selected configuration

Further Improvements being investigated

– Improve line length and thermal endurance

Dielectric (Conductor Insulation) Downselect

BAE SYSTEMS

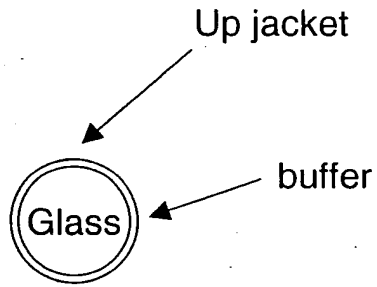
High performance Polymer Dielectrics

- Upilex-S is considered to be the best high temperature polymer film
  - Film is not manufactured with an adhesive for insulation wrapping
  - Upilex-S as a "varnish" is not yet "commercially" available
- Kapton H with FEP adhesive is a common high temperature insulation (rated to 260C)
  - Properties not a good as Upilex-S
- 'Mixing' Kapton H & Upilex-S is next best polymer film commercially available as Kapton E (new material)
  - Can be made with type KJ adhesive
    - Better performance than FEP or PFA adhesives
    - Material referred to as EKJ

EKJ Insulation Selected as Candidate
- **Driven by Original RFCM IB3 OPEVAL Schedule**

FO Coating (Buffer/Upjacket) Candidates and Downselect

BAE SYSTEMS



- Options Considered
  - Buffer
    - Carbon/Polyimide
    - Polyimide
    - Metalization/Polyimide
  - Upjacket
    - PFA (high temperature replacement for FEP)
    - PEEK (vendors could not support for Phase A testing)

Candidates Selected

Buffer:	**Carbon/Polyimide or Polyimide**
Upjacket:	**PFA or PEEK**
	• All Options Support 500°C Operation in the Lab

Towline and Signal Line Jacket Candidates and Downselect

BAE SYSTEMS

Options Considered

- Silicon Carbide
- Carbon
- Cobalt Nickel Superalloy
- Various Others

Options Tested

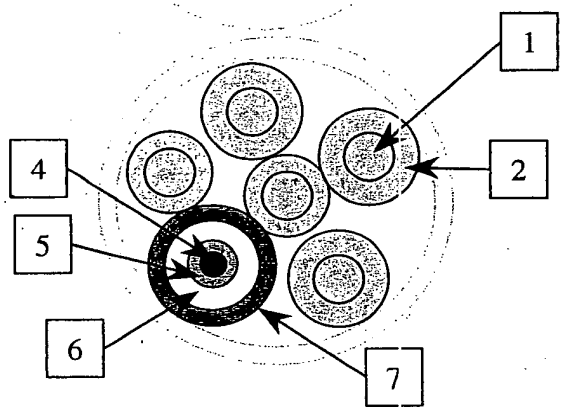
- Silicon Carbide
- Carbon
- Zylon

Zylon Selected as Candidate Material

- **Best Strength-to-Weight Ratio @ 500°C**

Cable System Flight Test Configurations

BAE SYSTEMS



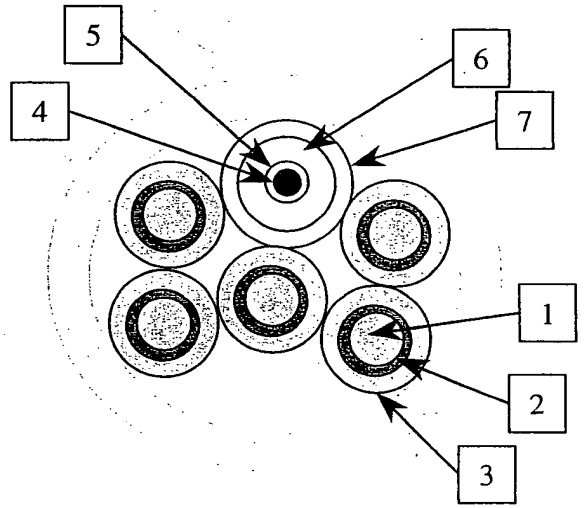
Baseline Cable System

Tow	
Baseline	**Upgrade**
2 Stage	3 Stage
12k / 9k denier	24k / 12k / 9k denier

Signal - Jacket	
Baseline	**Upgrade**
2k denier	9k / 3k denier 4k / 2k denier

Signal - Conductors		
	Baseline	**Upgrade**
1	**32 Ga copper**	**32 Ga copper**
2	**MIL-ENE** 0.002" / 0.003"	**PTFE** 0.0005"
3	**N/A**	**EKJ** 0.003" 0.004" 0.006"

Signal - Optics		
	Baseline	**Upgrade**
4	**Glass**	**Glass**
5	**Acrylate** 245 microns	**Polyimide** 152 microns
6	**PTFE** 0.003"	**PTFE** 0.003"
7	**FEP** 600 micron OD	**PFA and PEEK** 600 micron OD

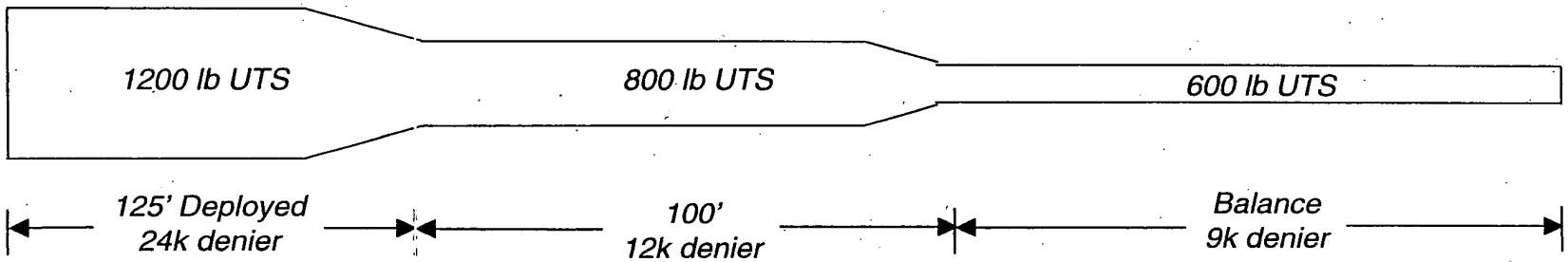


Upgrade Options

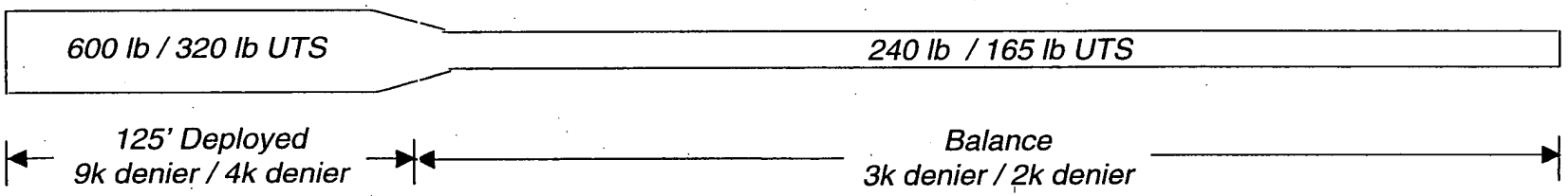
Cable System Flight Test Configurations

BAE SYSTEMS

Tow Cable



Signal Cable Jacket



Configuration	Tow	Signal Jacket	HV Insulation	FO Coating	FO Upjacket	Deploy Length
'G1	24K/12/9K	9K/3K	3 mil EKJ	Carbon	PFA	64%
'G2	24K/12/9K	9K/3K	4 mil EKJ	No Carbon	PEEK	48%
'G3	24K/12/9K	4K/2K	6 mil EKJ	Carbon	PFA	50%
'G4	24K/12/9K	9K/3K	4 mil EKJ	Carbon	PFA	59%
'G5	24K/12/9K	9K/3K	4 mil EKJ	No Carbon	PFA	59%

Flight Test Considerations

BAE SYSTEMS

Known Issues Entering Tests

- Carbon coating on glass reduces strength
  - Significant handling problems during assembly (BAE SYSTEMS and GORE)
  - 1 unit wired to show good continuity due to fiber breakage
  - Expected poor optical performance from carbon configuration prior to testing
- 0.006" EKJ puts additional stress on the PFA upjacketed fiber

F/A-18E/F Towline Durability Flight Test Results

BAE SYSTEMS

Configuration	Flights	Total H.V Electrical Continuity	Total Optical Time	Total A/B Time	AOA Achiev d		
					5 kft	15 kft	35 kft
0.003" EKJ Insulation Carbon/PFA Upjacket Launch Condition: 336 psf	4	368 minutes	Two successful flights totaling 197 minutes (1 hard wired good 1 failure at launch)	906 seconds	3°	3°	7°
0.006" EKJ Insulation Carbon/PFA Upjacket Launch Condition: 336 psf	2	20 minutes (Test box off on one test)	3 seconds (Both lost during launch)	274 seconds	2°	3°	7°
0.004" EKJ insulation No Carbon/PEEK Upjacket Launch Condition: 700 psf	2	36 minutes (Test box off on one test)	78 minutes (Both good to end of flight Cable damaged on Camera)	37 seconds (one flight done only with MIL power)	N/A	N/A	7°

Flight Test Results

BAE SYSTEMS

- No instances of tow line burnoff
  - Minimal damage seen
- 0.003" EKJ successfully passed all AOA conditions tested

  0.006" EKJ met 2 of 3 AOA conditions (4K denier jacket failed)
- 0.004" EKJ met test conditions @ 35 kft (not tested at 5 kft or 15 kft)
- Carbon/PFA
  - 3 of 5 failed at launch
  - 2 survived until test was terminated
- Non-carbon/PEEK
  - 2 flights at higher Launch Qs survived until test was terminated

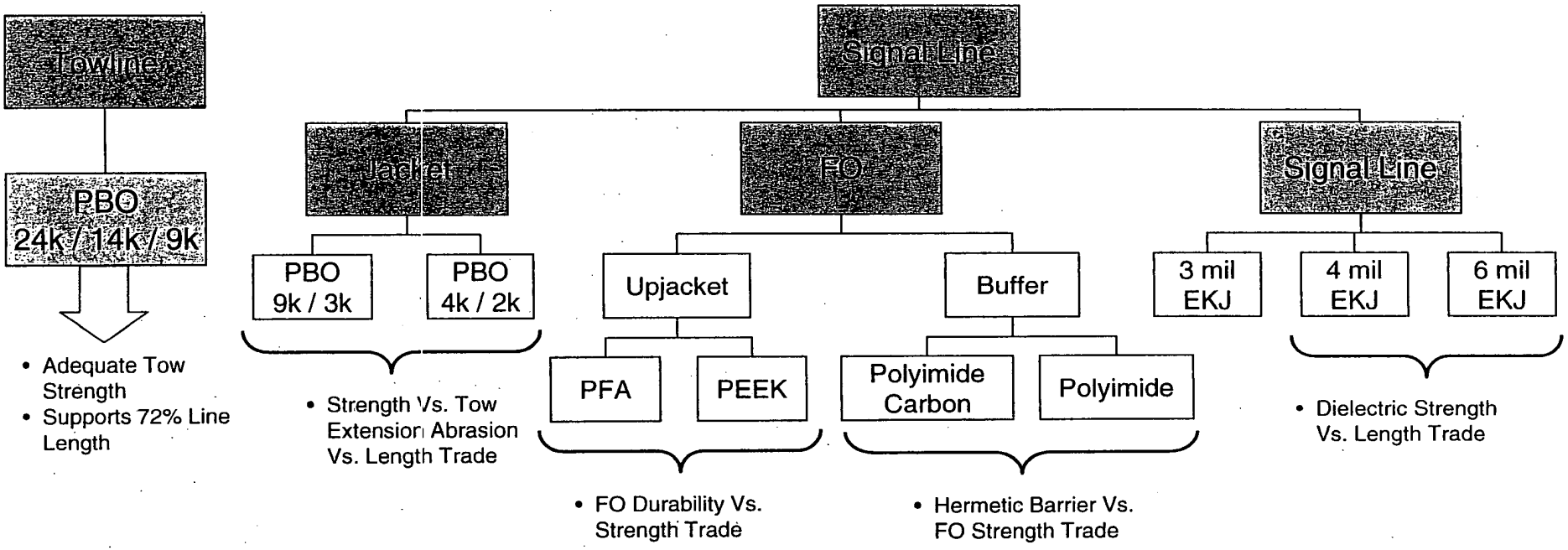
→ **Positive Strength Margin @ 24K Zylon**

→ **Positive Results w/EKJ**

→ **FO Performance Marginal w/Carbon**

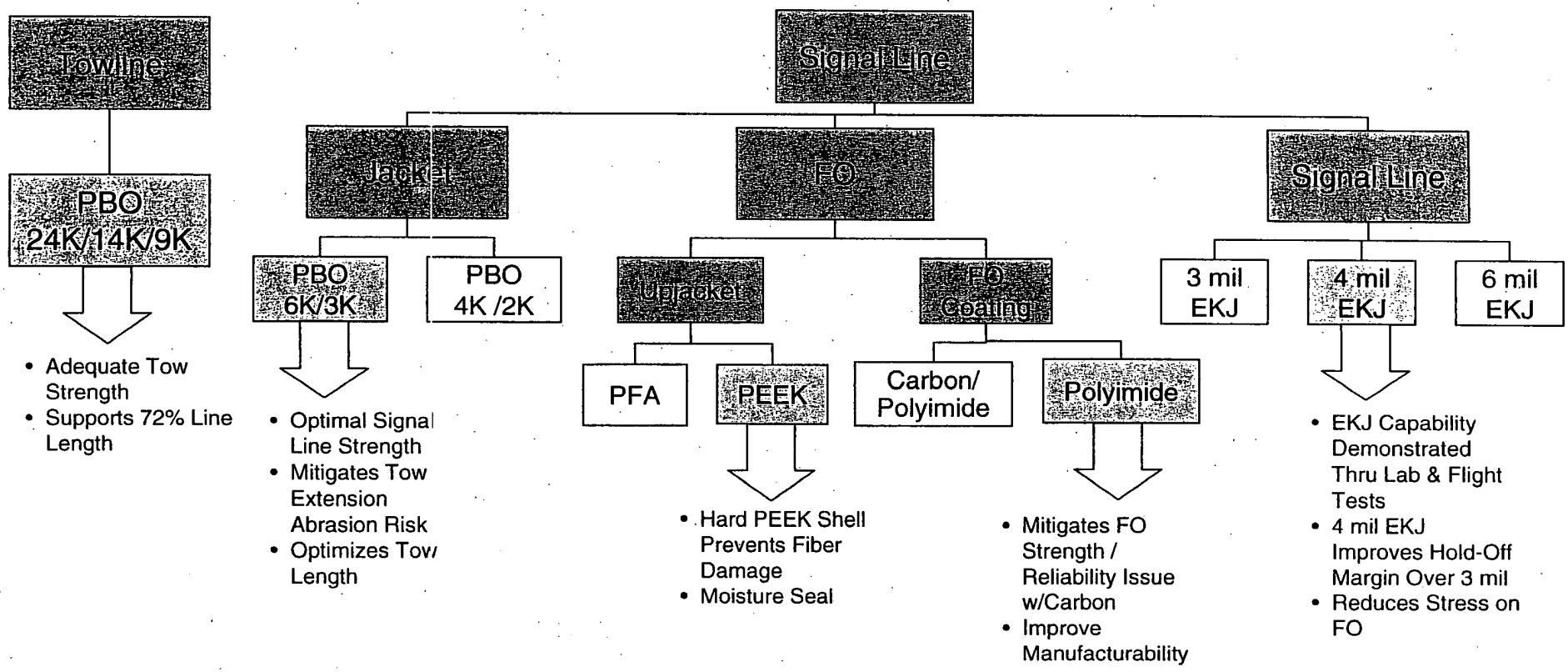
Cable Options Summary

BAE SYSTEMS



Downselected Configuration for Towline Upgrade (F/A-18E/F)

BAE SYSTEMS



Supports 58% Deployment Length

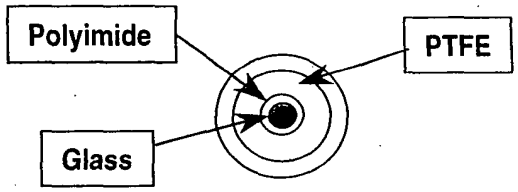
PEEK vs. PFA Upjacket Trade

BAE SYSTEMS

Flight data shows local damage, occurring during deployment, causes the highest stress

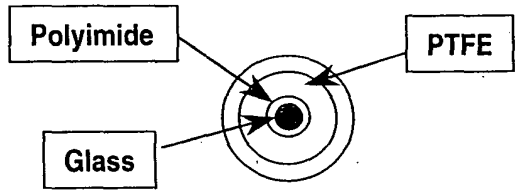
PFA allows greater length

- PFA (Like FEP) cold flows
- Mechanical deformation seen on
  - ✓ Wound spindles
  - ✓ Deployed signal line



Hard PEEK provides resistance to winding/deployment

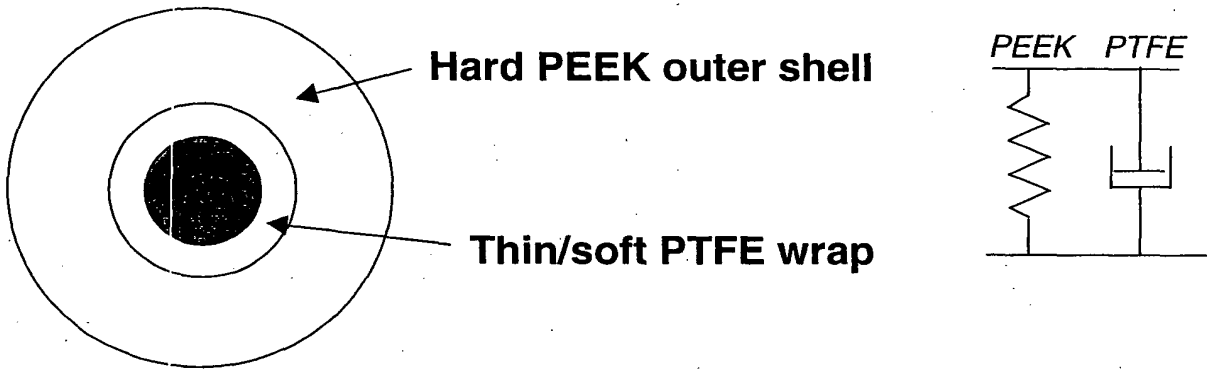
- No damage seen post wind/deployment
- Recovered field hardware shows no upjacket deformation
- Field return still continuous



PEEK/PTFE/FO Construction

BAE SYSTEMS

The stiff PEEK shell provides crushing protection during winding/storage/deployment



The soft PTFE layer allows the fragile glass to 'float' within the PEEK shell

- Absorbs energy during deployment
- Reduced thermal shock during plume exposure

Coating thickness reduction very possible to improve line length

PEEK and PTFE also protect the glass fiber from water